Copy No. _____

Defence Research and Development Canada
Recherche et développement pour la défense Canada

DEFENCE R&D DÉFENSE

Validation of ShipMo3D Version 1.0 User Applications for Simulation of Ship Motion

Kevin McTaggart

Defence R&D Canada – Atlantic

Technical Memorandum

DRDC Atlantic TM 2007-173

August 2007

Canada

This page intentionally left blank.

Validation of ShipMo3D Version 1.0 User Applications for Simulation of Ship Motions

Kevin McTaggart

Defence R&D Canada – Atlantic
Technical Memorandum
DRDC Atlantic TM 2007-173
August 2007

Principal Author

Original signed by Kevin McTaggart

Kevin McTaggart

Approved by

Original signed by Neil Pegg

Neil Pegg
Head/Warship Performance

Approved for release by

Original signed by J.L. Kennedy

J. L. Kennedy
Chair/Document Review Panel

Abstract

ShipMo3D is an object-oriented library with associated user applications for predicting ship motions in calm water and in waves. This report describes the validation of ShipMo3D user applications with data from model tests and full-scale trials. Seakeeping predictions have been validated with model tests for a steered warship model and with sea trials for a naval destroyer. Predicted RMS motions in random seas are typically within 10 to 30 percent of measured values, with heave motions being the most accurate and roll motions being the least accurate. Predicted zero-crossing periods for motions in random seas are typically within 10 percent of measured values. For the tanker Esso Osaka performing turning circle maneuvers, predicted turning circle parameters (tactical diameter, and speed and yaw rate at 1500 s), are within 18 percent of measured values from sea trials. Note that input data for the Esso Osaka included experimental hull maneuvering coefficients, and that less accurate results would be expected if maneuvering coefficients had to be estimated using other means.

Résumé

ShipMo3D est une bibliothèque orientée objet comportant des applications utilisateur permettant de prévoir le mouvement des navires dans des eaux calmes et dans les vagues. Le présent rapport décrit la validation des applications utilisateur de ShipMo3D à partir d'essais sur maquette et d'essais pleine échelle. Les prévisions relatives à la tenue en mer ont été validées lors des essais sur maquette pour un navire de guerre commandé et lors d'essais en mer pour un destroyer. Les mouvements (valeur quadratique moyenne de l'amplitude) prévus dans des mers à variations aléatoires se situent habituellement entre 10 et 30 pour cent de la valeur mesurée, les mouvements de tangage étant les plus précis et les mouvements de roulis étant les moins précis. Les périodes prévues de passage par zéro pour les mouvements dans des mers à variations aléatoires se situent habituellement dans une plage de 10 pour cent autour des valeurs mesurées. Dans le cas du navire pétrolier Esso Osaka effectuant des cercles de giration, les paramètres prévus des cercles de giration (diamètre tactique, vitesse finale totale du navire et vitesse finale de lacet) se situent habituellement dans une plage de 20 pour cent autour des valeurs mesurées. À noter que les données d'entrée pour le navire Esso Osaka comprenaient les coefficients de manœuvres expérimentales de la coque et qu'il faut s'attendre à des résultats moins précis lorsque les coefficients de manœuvre sont estimés par d'autres moyens.

This page intentionally left blank.

Executive summary

Validation of ShipMo3D Version 1.0 User Applications for Simulation of Ship Motions

Kevin McTaggart; DRDC Atlantic TM 2007-173; Defence R&D Canada – Atlantic; August 2007.

Introduction: ShipMo3D is an object-oriented library with associated user applications for predicting ship motions in calm water and in waves. Motion predictions are available in both the frequency domain and the time domain. For predictions in the frequency domain, a ship is assumed to travel with quasi-steady speed and heading in waves. For predictions in the time domain, the ship can be freely maneuvering in either calm water or in waves. This report documents the validation of ShipMo3D Version 1.0, the first release version of the library.

Principal Results: Seakeeping predictions have been validated with model tests for a steered warship model and with sea trials for a naval destroyer. Predicted RMS motions in random seas are typically within 10 to 30 percent of measured values, with heave motions being the most accurate and roll motions being the least accurate. Predicted zero-crossing periods for motions in random seas are typically within 10 percent of measured values. Agreement between ShipMo3D predictions in the frequency and time domains indicates consistency between formulations.

For the tanker Esso Osaka performing turning circle maneuvers, predicted turning circle parameters (tactical diameter, and speed and yaw rate at 1500 s), are within 18 percent of measured values from sea trials. Note that input data for the Esso Osaka included experimental hull maneuvering coefficients, and that less accurate results would be expected if predicted maneuvering coefficients were used.

Significance of Results: The present validation results indicate that ShipMo3D is giving generally good agreement with experimental results, and provide estimates of the level of uncertainty that can be expected with ship motion predictions. ShipMo3D gives accuracy comparable to other ship motion prediction methods for ships travelling at moderate speeds, which would include modern naval frigates travelling at speeds of 30 knots and lower.

Future Plans: Additional ship motion prediction capabilities are being developed using ShipMo3D. The modelling of azimuthing propulsors, such as Z-drives, is being introduced. User applications are being developed for predicting motions of two ships in close proximity, including the modelling of hydrodynamic interactions.

Sommaire

Validation of ShipMo3D Version 1.0 User Applications for Simulation of Ship Motions

Kevin McTaggart ; DRDC Atlantic TM 2007-173 ; R & D pour la défense Canada – Atlantique ; août 2007.

Introduction : ShipMo3D est une bibliothèque orientée objet comportant des applications utilisateur permettant de prévoir le mouvement des navires dans des eaux calmes et dans les vagues. Les prévisions relatives au mouvement sont disponibles à la fois pour le domaine des fréquences et le domaine temporel. Dans le cas des prévisions dans le domaine des fréquences, on suppose que le navire se déplace à vitesse presque constante et qu'il met le cap sur les vagues. Dans le cas des prévisions relatives au domaine temporel, le navire peut manœuvrer librement, soit dans des eaux calmes ou dans les vagues. Le présent rapport documente la validation de la version 1.0 de ShipMo3D, qui est la première version publiée de la bibliothèque.

Résultats principaux : Les prévisions relatives à la tenue en mer ont été validées lors des essais sur maquette pour un navire de guerre commandé, et lors d'essais en mer pour un destroyer. Les mouvements (valeur quadratique moyenne de l'amplitude) prévus dans des mers à variations aléatoires se situent habituellement entre 10 et 30 pour cent de la valeur mesurée, les mouvements de tangage étant les plus précis et les mouvements de roulis étant les moins précis. Les périodes prévues de passage par zéro pour les mouvements dans des mers à variations aléatoires se situent habituellement dans une plage de 10 pour cent autour des valeurs mesurées. La concordance entre les prévisions de ShipMo3D dans le domaine des fréquences et le domaine temporel laisse supposer une certaine uniformité dans les formulations.

Dans le cas du navire pétrolier Esso Osaka effectuant des cercles de giration, les paramètres prévus des cercles (diamètre tactique, vitesse finale totale du navire et vitesse finale de lacet) se situent habituellement dans une plage de 20 pour cent autour des valeurs mesurées. À noter que les données d'entrée pour le navire Esso Osaka comprenaient les coefficients de manœuvres expérimentales de la coque et qu'il faut s'attendre à des résultats moins précis lorsque les coefficients de manœuvre sont estimés par d'autres moyens.

Importance des résultats : Les résultats actuels de la validation indiquent que ShipMo3D offre généralement une bonne concordance avec les résultats expérimentaux et fournissent des estimations du niveau d'incertitude pouvant être attendu des pré-vi-sions du mouvement des navires. ShipMo3D offre une précision comparable à celle

des autres méthodes de prévision du mouvement des navires qui se déplacent à vitesse modérée, ce qui comprend les frégates se déplaçant à des vitesse de 30 nœuds et moins.

Travaux ultérieurs prévus : On travaille actuellement à la mise au point d'autres capacités de prévision du mouvement des navires à l'aide de ShipMo3D. La modél-i-sa-tion des systèmes propulseurs orientables en azimut, comme les moteurs à propulsion en Z, y est présentée. Les applications utilisateur sont mises au point afin de prévoir les mouvements de deux navires évoluant à proximité immédiate, en modélisant les interactions hydrodynamiques.

This page intentionally left blank.

Table of contents

List of tables

List of figures

This page intentionally left blank.

1 Introduction

ShipMo3D is an object-oriented library and associated applications for predicting ship motions in both the frequency and time domains. Frequency domain predictions of ship motions in waves are based on the assumption that a ship is travelling with nominally steady speed and heading. Time domain predictions can determine the motions of a freely maneuvering ship in calm water or in waves. Hull radiation and diffraction forces are evaluated using the boundary element method and the three dimensional Green function for zero forward speed; thus, ShipMo3D can be expected to give good results for both slender and non-slender vessels travelling at moderate Froude numbers ($U/\sqrt{gL} < 0.5$, where U is ship forward speed, g is gravitational acceleration, and L is ship length between perpendiculars).

Initial development of ShipMo3D considered a ship travelling with nominally steady speed and heading in a seaway. Frequency domain predictions of hull hydrodynamic forces were completed in Reference 1, and were subsequently extended to time domain predictions [2]. ShipMo3D can model both regular and random seaways [3], with modelled random seaways that can be either unidirectional or multidirectional. Appendage and viscous hull forces, which are essential for predicting sway, roll, and yaw motions, were introduced in Reference 4. Subsequent work extended ShipMo3D time domain predictions to model freely maneuvering ships in calm water and in waves [5, 6].

Several ShipMo3D user applications are available for predicting ship motions in the frequency and time domains [7, 8]. These applications read input files of specified formats and write computational results to output files. Some graphical output is also available, such as three dimensional drawings of input ship geometries and two dimensional plots of predicted hydrodynamic coefficients and ship motions.

This report gives validation results for ShipMo3D predictions of motions in waves and maneuvering in calm water. All validation results were obtained with ShipMo3D user applications (i.e., the validation results were not obtained using separate programs that access the ShipMo3D library); thus, the validation computations can be replicated by any ShipMo3D user. The present work is based on ShipMo3D Version 1.0, which is considered to be the initial stable release of the library. Although some ongoing improvements are expected to be made to ShipMo3D, it is considered to be sufficiently mature that required changes will be infrequent.

Section 2 gives validation of motions in waves for a steered warship model travelling in waves of small steepness [9]. Validation of motions in waves during sea trials for the Canadian destroyer HMCS NIPIGON [10] is given in Section 3. Section 4 gives validation for sea trials of turning circles for the tanker Esso Osaka. Final conclusions are given in Section 5.

2 Wave-Induced Motions of the Haslar Steered Warship from Model Tests in Regular Waves

Lloyd and Crossland [9] published results of model tests for a steered warship model travelling in regular waves of small steepness. The model was tested in the seakeeping basin of the Admiralty Marine Technology Establishment (Haslar), which is now part of QinetiQ Limited in the United Kingdom. The experimental program included comprehensive ranges of ship speeds, relative sea directions, and wave frequencies. The model was self-propelled and was steered using an autopilot. Due to the wide range of test conditions, the control of the experimental conditions, and the range of data collected, this is likely the best set of experimental data available in the open literature for validating ship motion predictions at moderate speeds in moderate seaways.

2.1 Haslar Steered Warship Model

The steered warship model can be considered to be a nominally 1/20 scale model of a naval frigate or destroyer. Table 1 gives the main particulars for the steered warship model, and Figure 1 shows the body plan. Tables 2 to 5 give dimensions for the bilge keels, propeller shaft brackets, stabilizer fins, and rudders. Some of the longitudinal locations of appendages in Tables 2 to 5 have corrections from Reference 9, which were provided by one of the original authors.

Table 1: *Main Particulars for Haslar Steered Warship Model*

Length, L	5580 mm
Beam, B	671 mm
Midships draft, T_{mid}	196 mm
Trim by stern, t_{stern}	0 mm
Displacement, $\triangle$	345 kg
Vertical centre of gravity, $\overline{KG}$	276 mm
Metacentric height, $\overline{GM}$	76 mm
Roll radius of gyration, r_{xx}	257 mm
Pitch radius of gyration, r_{yy}	1293 mm
Yaw radius of gyration, r_{zz}	1265 mm

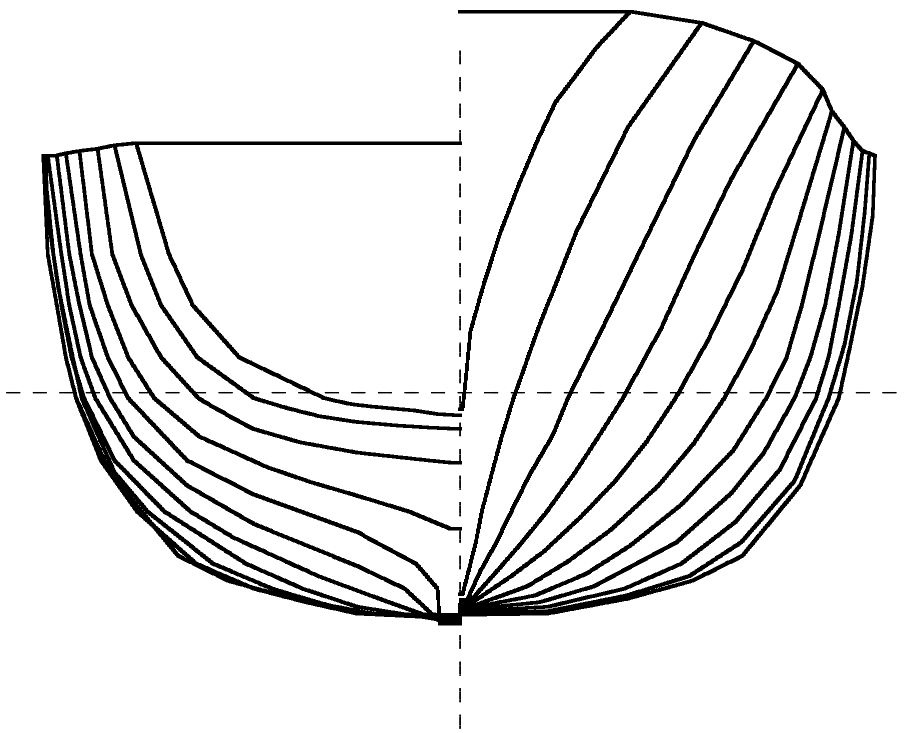

Figure 1: *Body Plan for Haslar Steered Warship Model*

Table 2: *Bilge Keel Dimensions for Haslar Steered Warship Model*

Station (20 at AP)	6.79	7	8	9	9.69
Span (mm)	68	68	68	68	68
Root lateral offset (mm)	239	239	243	248	248
Root above baseline (mm)	107	107	82	64	64
Dihedral angle (deg, port side)	-45	-45	-45	-45	-45

Table 3: *Propeller Shaft Bracket Dimensions for Haslar Steered Warship Model*

	Aft inner bracket	Aft outer bracket	Fore inner bracket	Fore outer bracket
Station (20 at AP)	18.40	18.40	17.97	17.97
Span (mm)	165	127	81	68
Root chord (mm)	30	30	12	12
Tip chord (mm)	30	30	12	12
Root lateral offset (mm)	21	132	72	157
Root above baseline (mm)	148	163	103	125
Dihedral angle (deg, port side)	-47.5	-99.5	-42	-90

Table 4: *Stabilizer Fin Dimensions for Haslar Steered Warship Model*

Station (20 at AP)	10.38
Span (mm)	83
Root chord (mm)	174
Tip chord (mm)	92
Root lateral offset (mm)	273
Root above baseline (mm)	75
Dihedral angle (deg, port side)	-46

Table 5: *Rudder Dimensions for Haslar Steered Warship Model*

Station (20 at AP)	19.46
Span (mm)	153
Root chord (mm)	124
Tip chord (mm)	88
Root lateral offset (mm)	79
Root above baseline (mm)	178
Dihedral angle (deg, port side)	-83

ShipMo3D models a proportional-integral-derivative (PID) autopilot [6], with the command rudder angle determined as follows:

$$\delta_C^{rudder} = \sum_{j=1}^{6} \left[k_{\delta j}^P \left(\eta_j^f - \eta_{Cj}^f \right) + k_{\delta j}^I \int_0^{\tau_{max}^{rudder}} \left(\eta_j^f (t-\tau) - \eta_{Cj}^f \right) d\tau + k_{\delta j}^D \dot{\eta}_j^f \right] \quad (1)$$

where δ_C^{rudder} is the command rudder angle, $k_{\delta j}^P$ is the proportional gain for mode j, η_j^f is the motion displacement in earth-fixed axes for mode j, η_{Cj}^f is the command motion displacement for mode j, $k_{\delta j}^I$ is the integral gain for mode j, τ_{max}^{rudder} is the integration duration, t is the current time, τ is the time delay for integration, $k_{\delta j}^D$ is the derivative gain for mode j, and $\dot{\eta}_j^f$ is the motion velocity in earth-fixed axes for mode j. For a given command rudder angle δ_C^{rudder}, which can be provided by the autopilot or by a helmsman, the rudder response is modelled as follows:

$$\ddot{\delta}^{rudder} + 2\,\zeta_\delta\,\omega_\delta^{rudder}\,\dot{\delta}^{rudder} + \omega_\delta^2\,\delta^{rudder} = \omega_\delta^2\,\delta_C^{rudder} \quad (2)$$

where ζ_δ is the nondimensional damping response constant, and ω_δ is the rudder frequency response constant.

The steered warship model included an autopilot with control parameters as given in Table 6. The yaw autopilot gains are based on the ShipMo3D convention of earth-fixed yaw being positive clockwise when viewed from above, and rudder deflection being positive counter-clockwise when viewed from inside the ship (i.e., positive counter-clockwise when viewed from above for a typical downward rudder stock).

Table 6: *Rudder Control Properties for Haslar Steered Warship Model*

Maximum deflection angle δ_{max}^{rudder}	35 deg
Maximum deflection rate $\dot{\delta}_{max}^{rudder}$	35 deg/s
Deflection natural frequency ω_δ	25.8 rad/s
Deflection damping ratio ζ_δ	0.85
Yaw displacement gain $k_{\delta 6}^P$	-3.8
Yaw velocity gain $k_{\delta 6}^D$	-1.7 s

2.2 ShipMo3D Input Files for Haslar Steered Warship Model

Annex A gives ShipMo3D input files for the Haslar steered warship model. For brevity, this report doesn't give ShipMo3D output files.

Annex A.1 gives the SM3DPanelHull input file for panelling the hull. This file uses the file *swPatch.inp* (Annex A.2), which has required hull geometric data. SM3DPanelHull models the hull as the following surfaces represented by bidirectional B-splines:

- forward portion of keel from station -1 to station 0 (station 0 is located at the fore perpendicular, and station 20 is located at the aft perpendicular),
- main portion of keel from station 0 to station 20,
- forward portion of hull from station -1 to station 0,
- main portion of hull from station 0 to station 20,
- transom,
- forward portion of deck from station -1 to station 0,
- main portion of deck from station 0 to station 20.

Annex A.3 gives the SM3DRadDif input file for radiation and diffraction computations. SM3DRadDif was run more than once such that appropriate limits on condition numbers could be selected for suppression of irregular frequencies.

Annex A.4 gives the SM3DBuildShip input file for creating a time domain model of the ship. A very similar input file is used for creating a frequency domain model of the ship, with changes made to the *shipType* option and the name of the ship model output file specified in the *shipDBFileName* record. Figure 2 shows graphical output of the ship model from SM3DBuildShip.

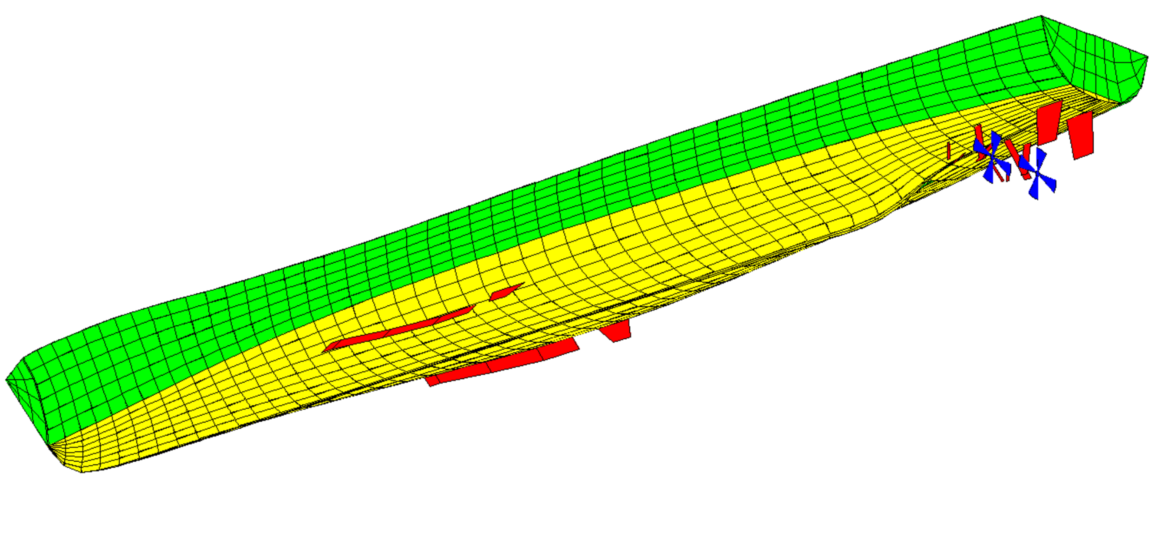

Figure 2: *ShipMo3D Model for Haslar Steered Warship Model*

Due to lack of available data, some of the input parameters for the steered warship model had to be estimated. Hull resistance was estimated using the method of Holtrop and Mennen [11], which is available as an option in SM3DBuildShip. The variation of propeller thrust coefficient with advance ratio was based on a representative curve from Reference 12. For each rudder, the rudder-propeller coefficient associated with the propeller on the same side of the ship was given a value of 0.9, based on the assumption that 90 percent of the rudder area was within the propeller slipstream. The flow straightening coefficient for each rudder was estimated to be 0.7 based on the following equation from Lewandowski [13]:

$$\gamma_r \approx \frac{1}{1 + C_B} \tag{3}$$

where C_B is the ship block coefficient.

For each ship speed used for model tests, the associated propeller RPM settings for calm water were determined using SM3DBuildShip, which uses an iterative process.

Annex A.5 gives the SM3DSeakeepRegular input file swSeakeepRegular.inp for predicting motions in the frequency domain for regular seas. This single input file covered all combinations of relative sea direction, Froude number, and wave frequency.

Annex A.6 gives the SM3DBuildSeaway input file for building a regular seaway with a wave frequency of 2.0 rad/s and wave steepness of 1/50. Similar input files were used to build seaways to a maximum wave frequency of 4.6 rad/s, with a wave frequency increment of 0.1 rad/s.

Annex A.7 gives the SM3DFreeMo input file for predicting motions of a freely maneuvering ship in the time domain. The sample input file is for a relative sea direction of 0 degrees, Froude number of 0.18, and wave frequency 2.0 rad/s. Similar input files were created for all relevant combinations of relative sea direction, Froude number, and wave frequency. For both the model tests and numerical simulations, the ship had an initial forward speed of zero, and motion statistics were sampled after the ship had sufficient time to reach equilibrium speed.

2.3 Comparisons of Numerical Predictions and Experimental Results for Haslar Steered Warship Model in Regular Waves

Figures 3 to 19 show comparisons of ShipMo3D frequency and time domain predictions with experimental results for the steered warship model. The experimental data include additional results provided directly by QiniteQ that were not published in Reference 9.

Comparisons between experimental results and predictions are generally good, and time domain predictions give very good agreement with frequency domain predictions. As expected, vertical plane predictions are generally better than lateral plane predictions. For some of the plots (e.g., Figure 7), there are gaps in predictions for certain wave frequency ranges because predictions weren't made at encounter frequencies below 0.41 rad/s.

Pitch predictions are generally good, with somewhat poorer agreement with experiments at headings of 60 and 75 degrees (stern quartering seas). Low encounter frequencies occur at these headings, violating assumptions made when predicting hull hydrodynamic forces.

There is a noticeable underprediction of roll in Figure 7, which could be partly caused by the violation of assumptions of low forward speed and high encounter frequency when predicting hull potential flow forces. In bow quartering seas, Figures 17 and 18 show underprediction of roll, and to a lesser extent yaw. At present there is no known reason for this trend in bow quartering seas.

Differences between time domain and frequency domain predictions, which are most noticeable at lower wave frequencies, are likely due to neglecting the influence of the propeller slipstream on rudder forces during frequency domain computations.

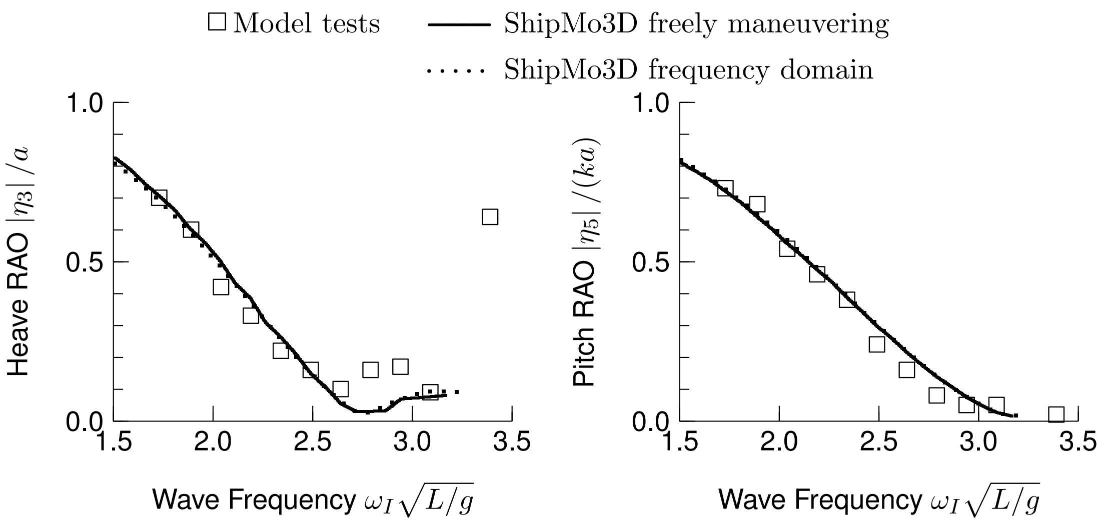

Figure 3: *RAOs for Steered Warship, Following Seas at 0 degrees, Froude Number 0.28*

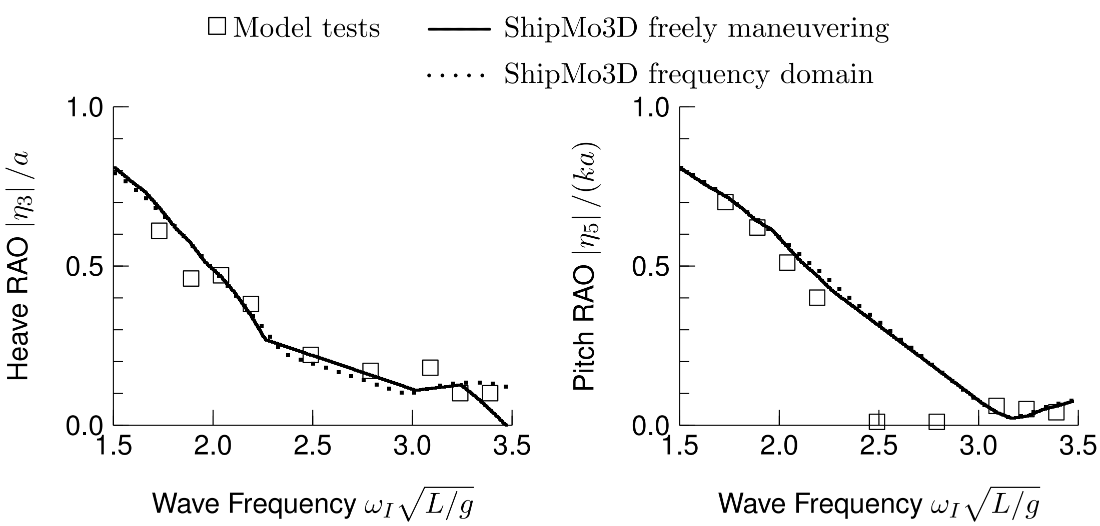

Figure 4: *RAOs for Steered Warship, Following Seas at 0 degrees, Froude Number 0.37*

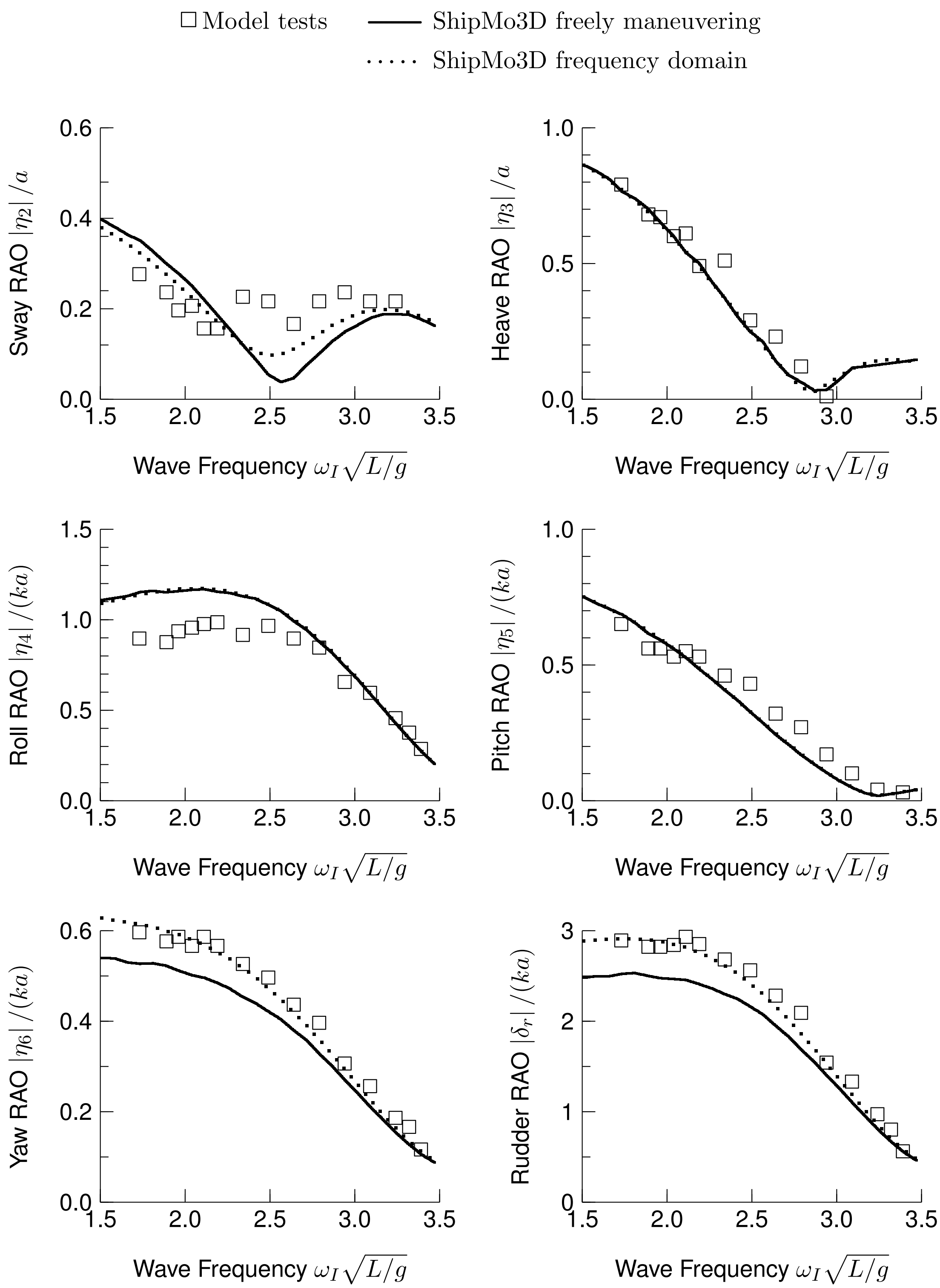

Figure 5: *RAOs for Steered Warship, Stern Quartering Seas at 30 degrees, Froude Number 0.18*

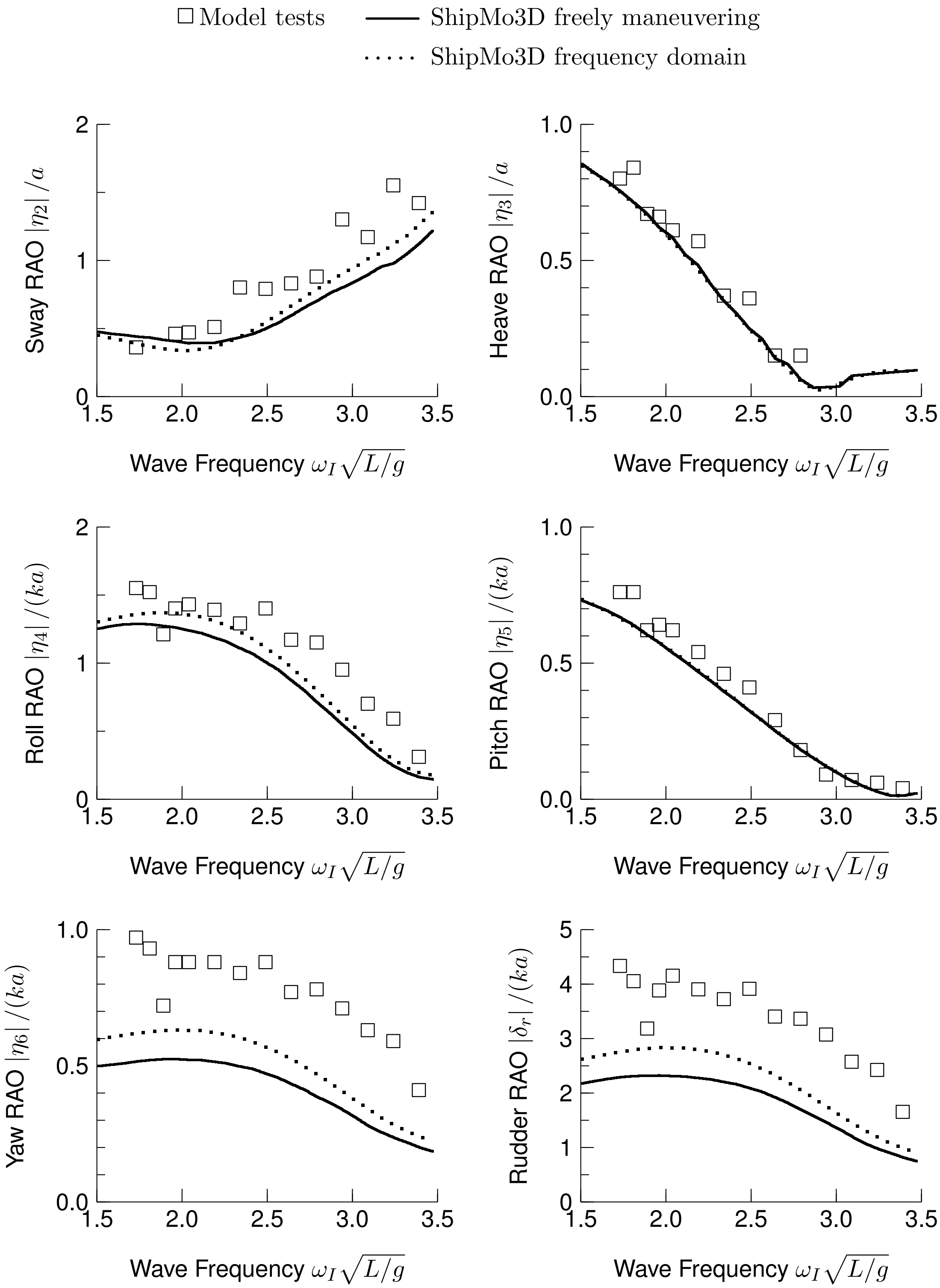

Figure 6: *RAOs for Steered Warship, Stern Quartering Seas at 30 degrees, Froude Number 0.27*

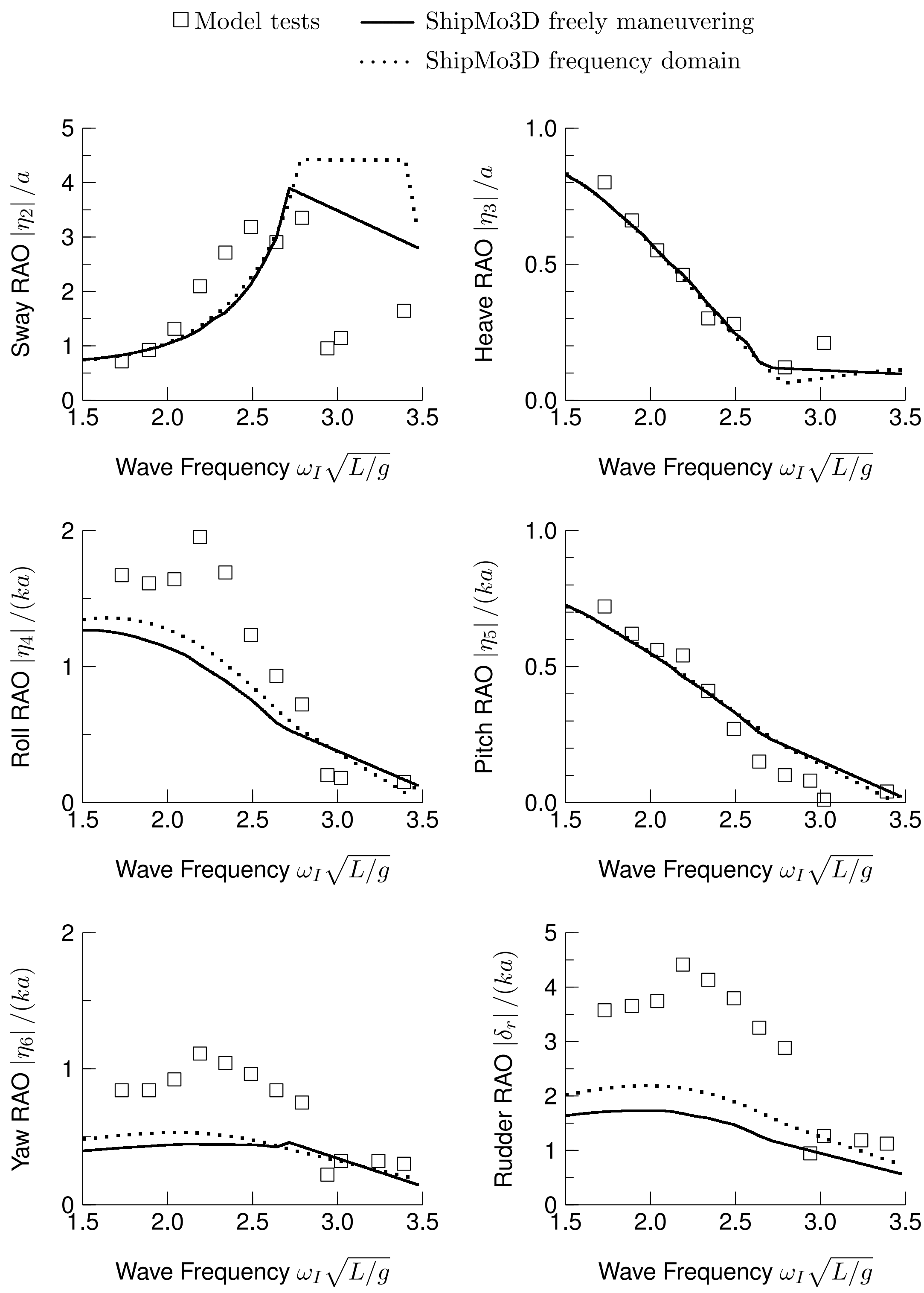

Figure 7: *RAOs for Steered Warship, Stern Quartering Seas at 30 degrees, Froude Number 0.37*

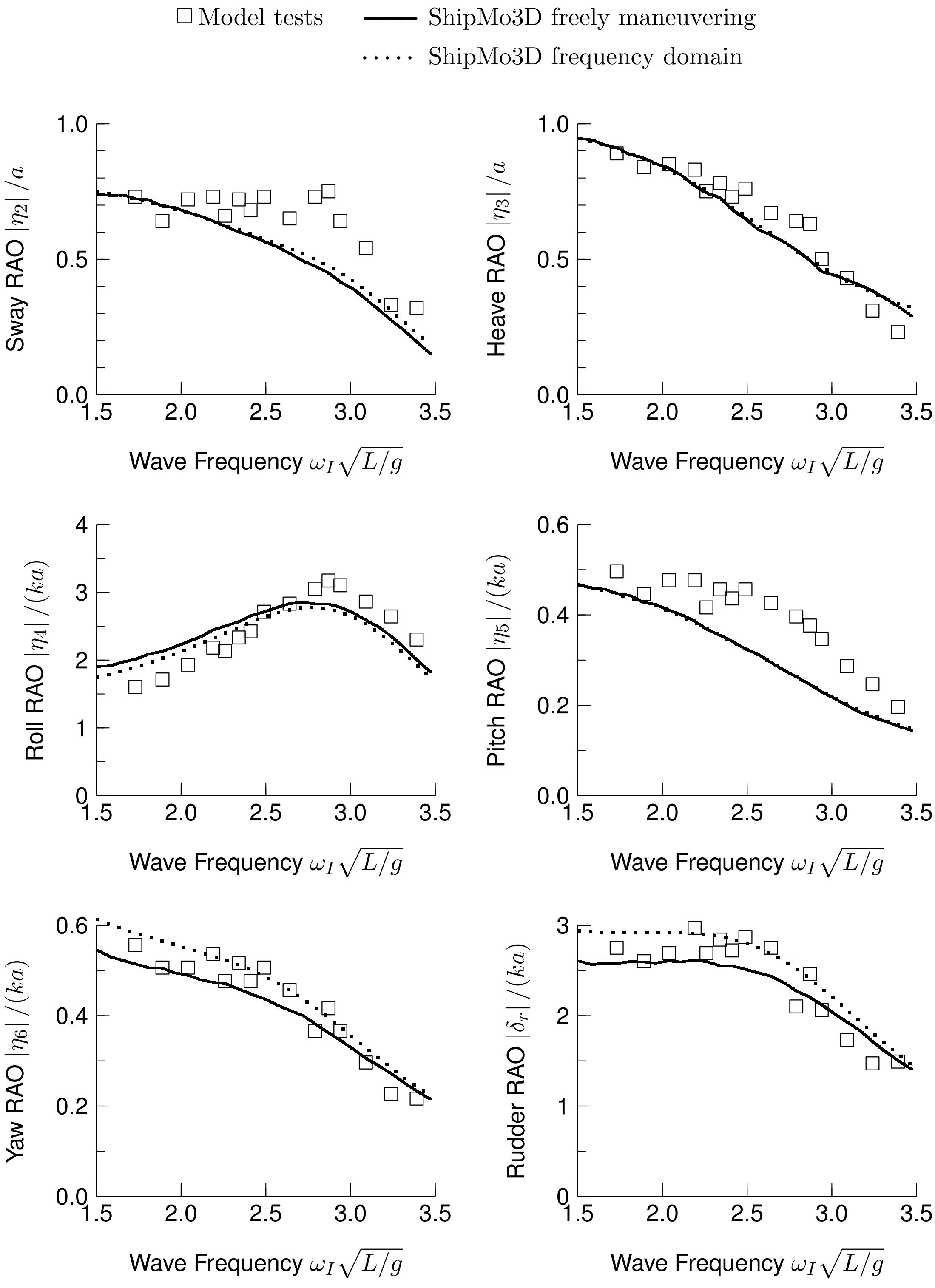

Figure 8: *RAOs for Steered Warship, Stern Quartering Seas at 60 degrees, Froude Number 0.18*

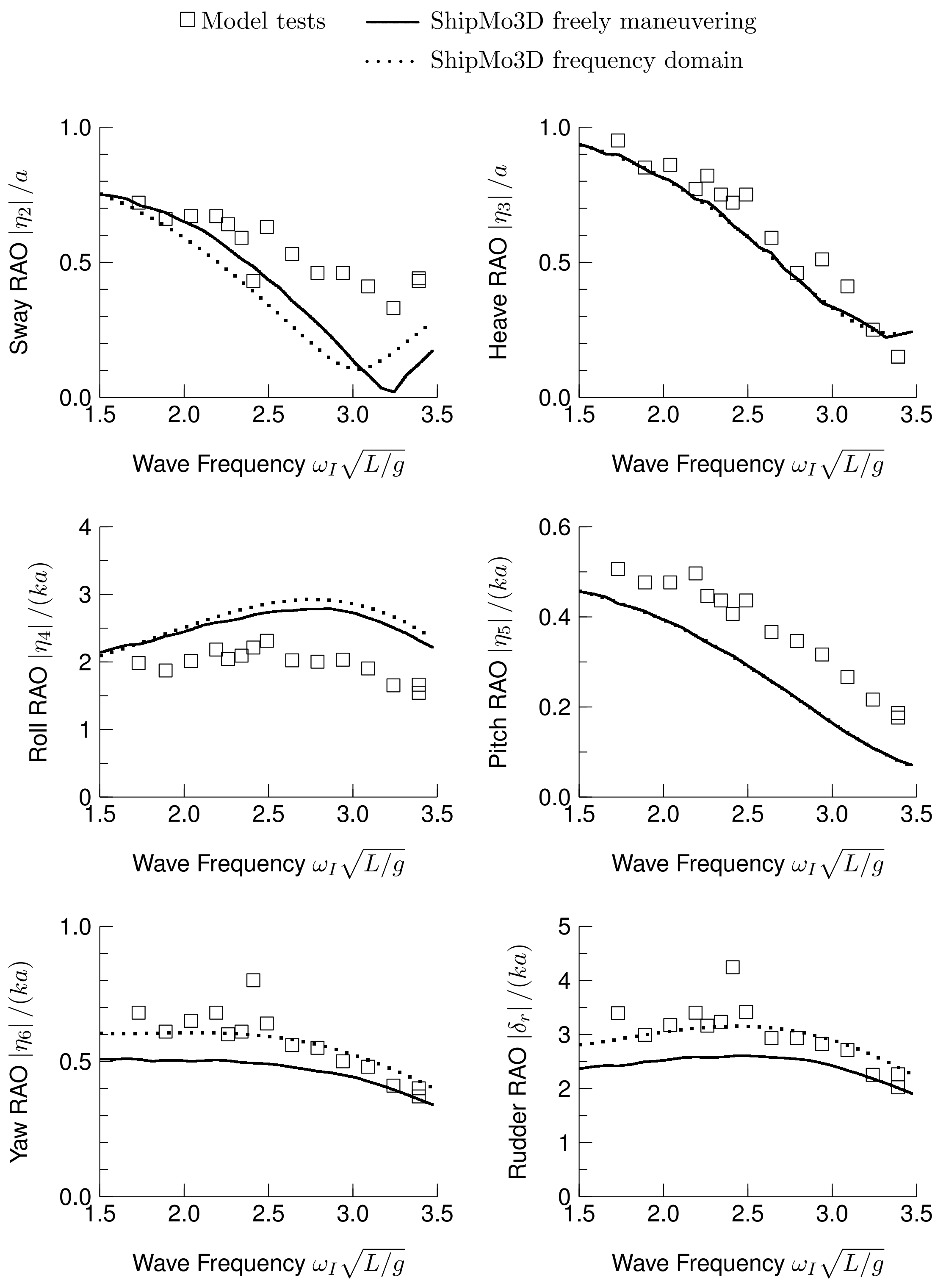

Figure 9: *RAOs for Steered Warship, Stern Quartering Seas at 60 degrees, Froude Number 0.27*

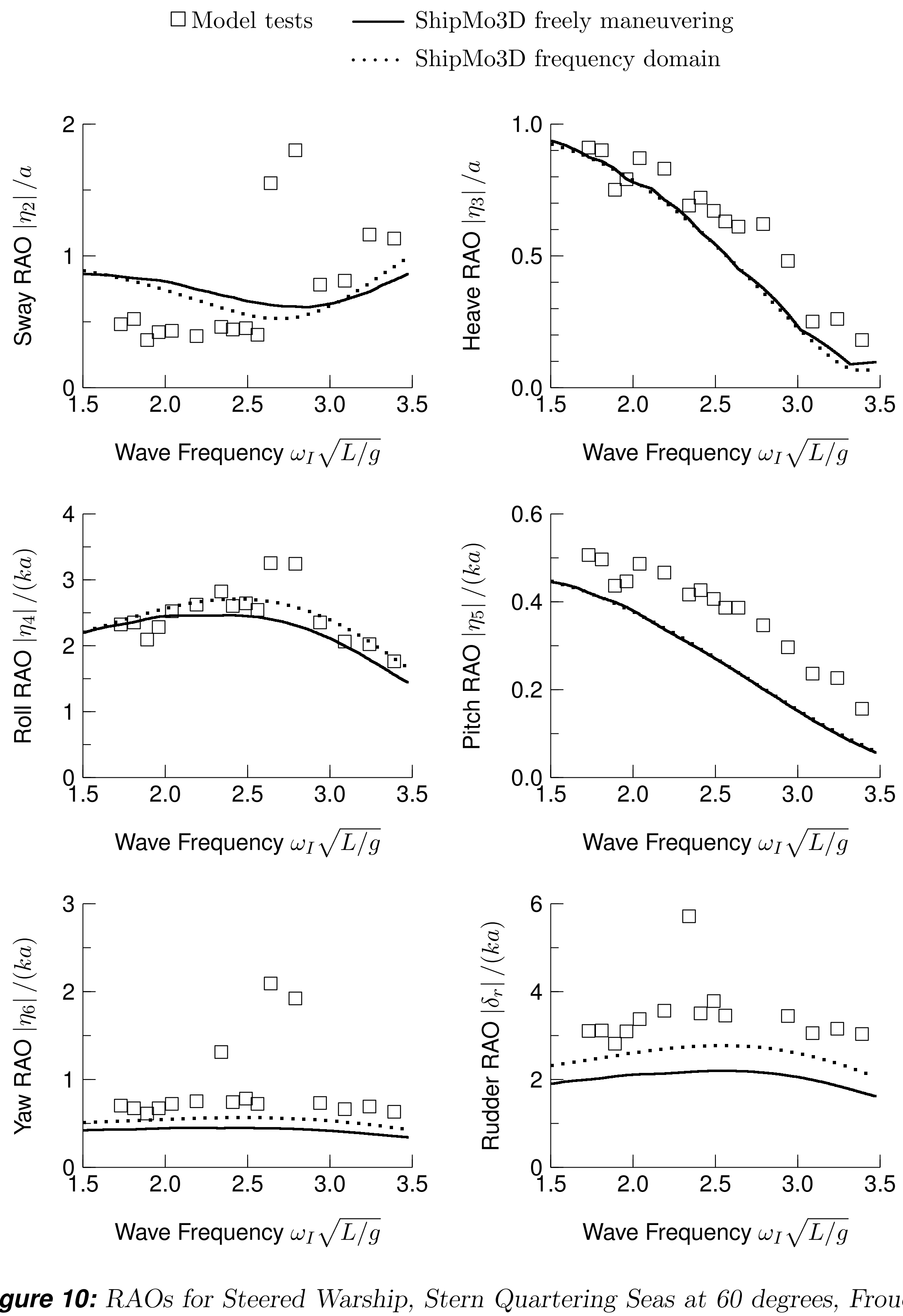

Figure 10: *RAOs for Steered Warship, Stern Quartering Seas at 60 degrees, Froude Number 0.36*

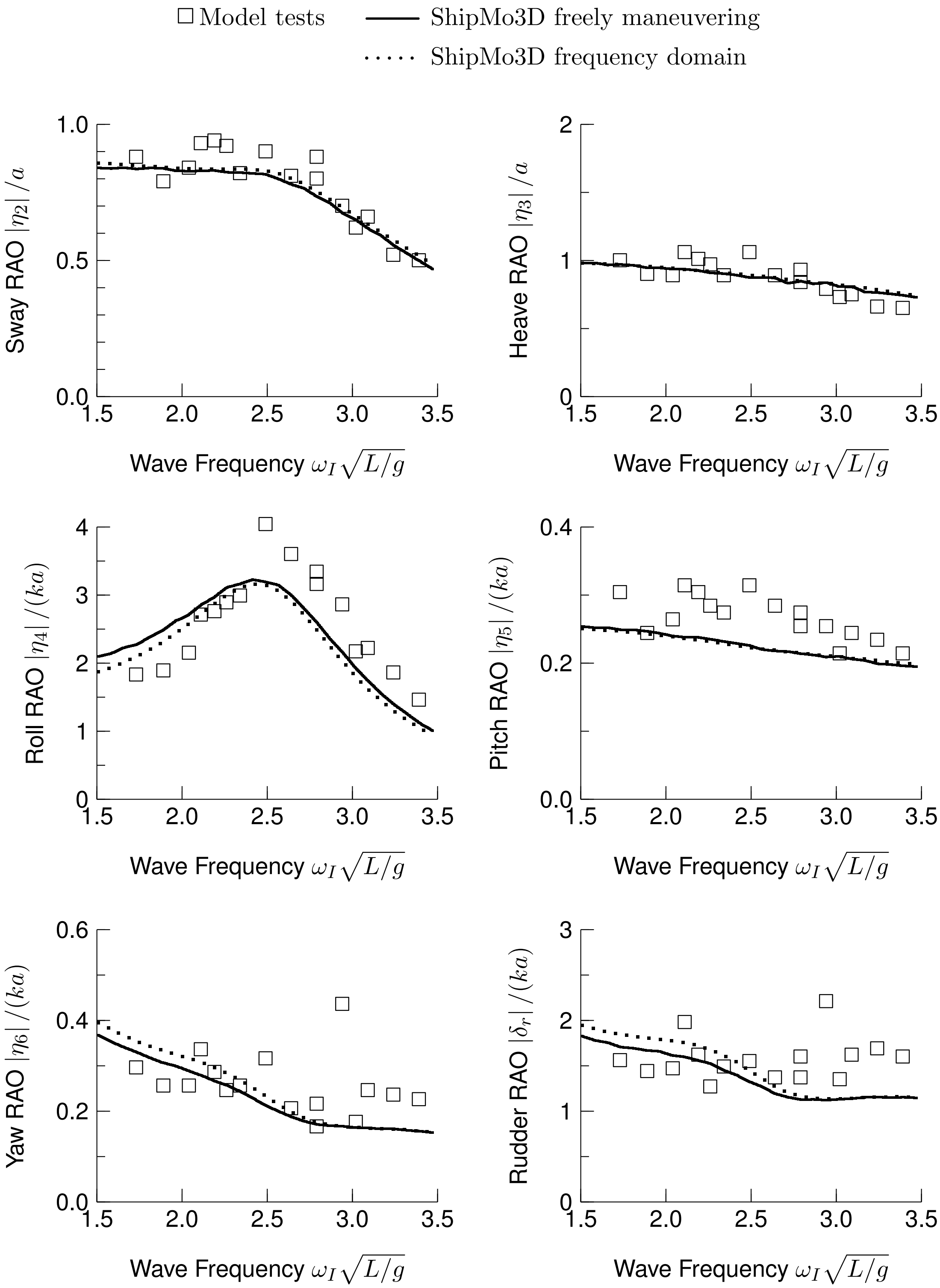

Figure 11: *RAOs for Steered Warship, Stern Quartering Seas at 75 degrees, Froude Number 0.18*

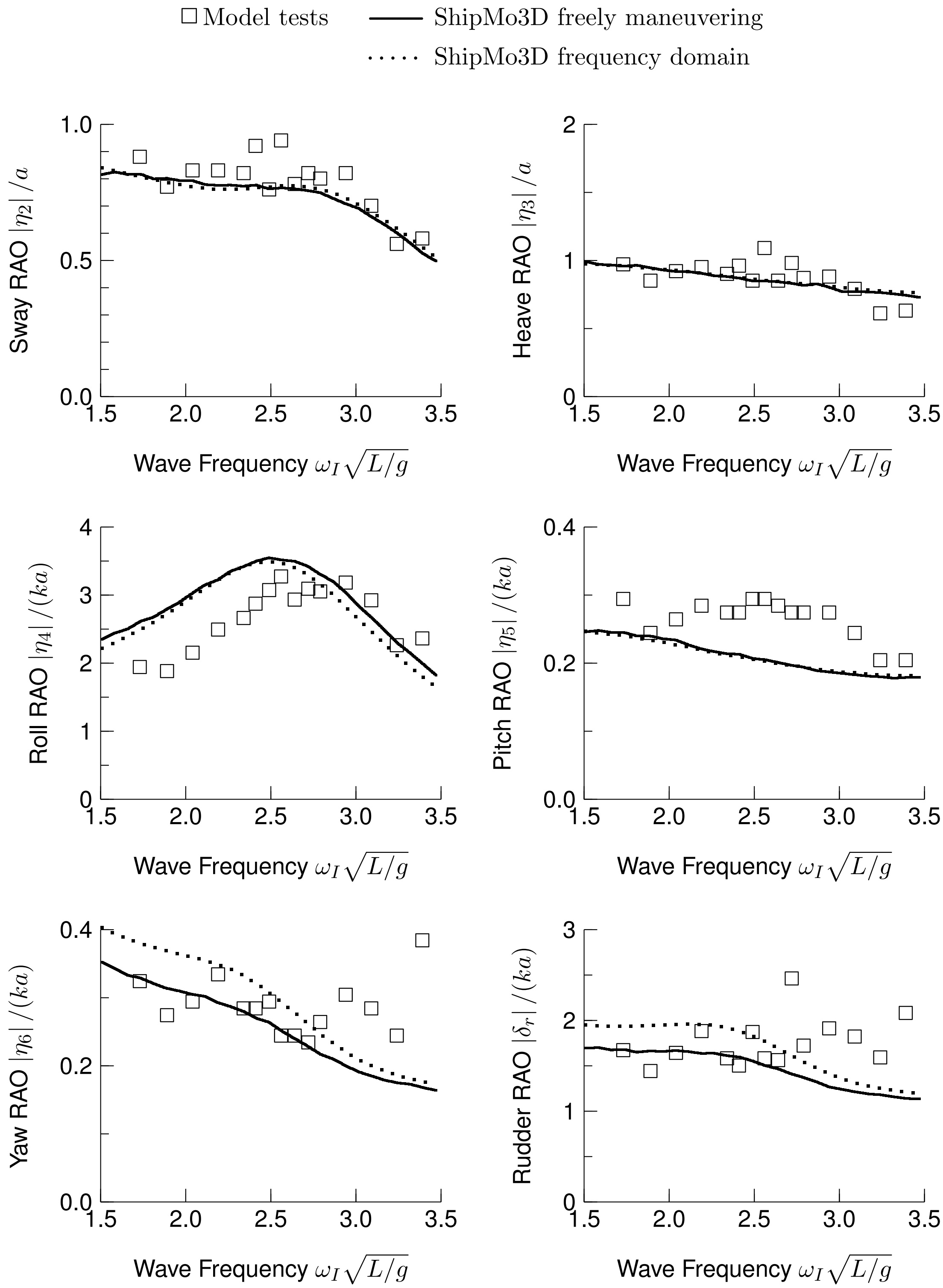

Figure 12: *RAOs for Steered Warship, Stern Quartering Seas at 75 degrees, Froude Number 0.28*

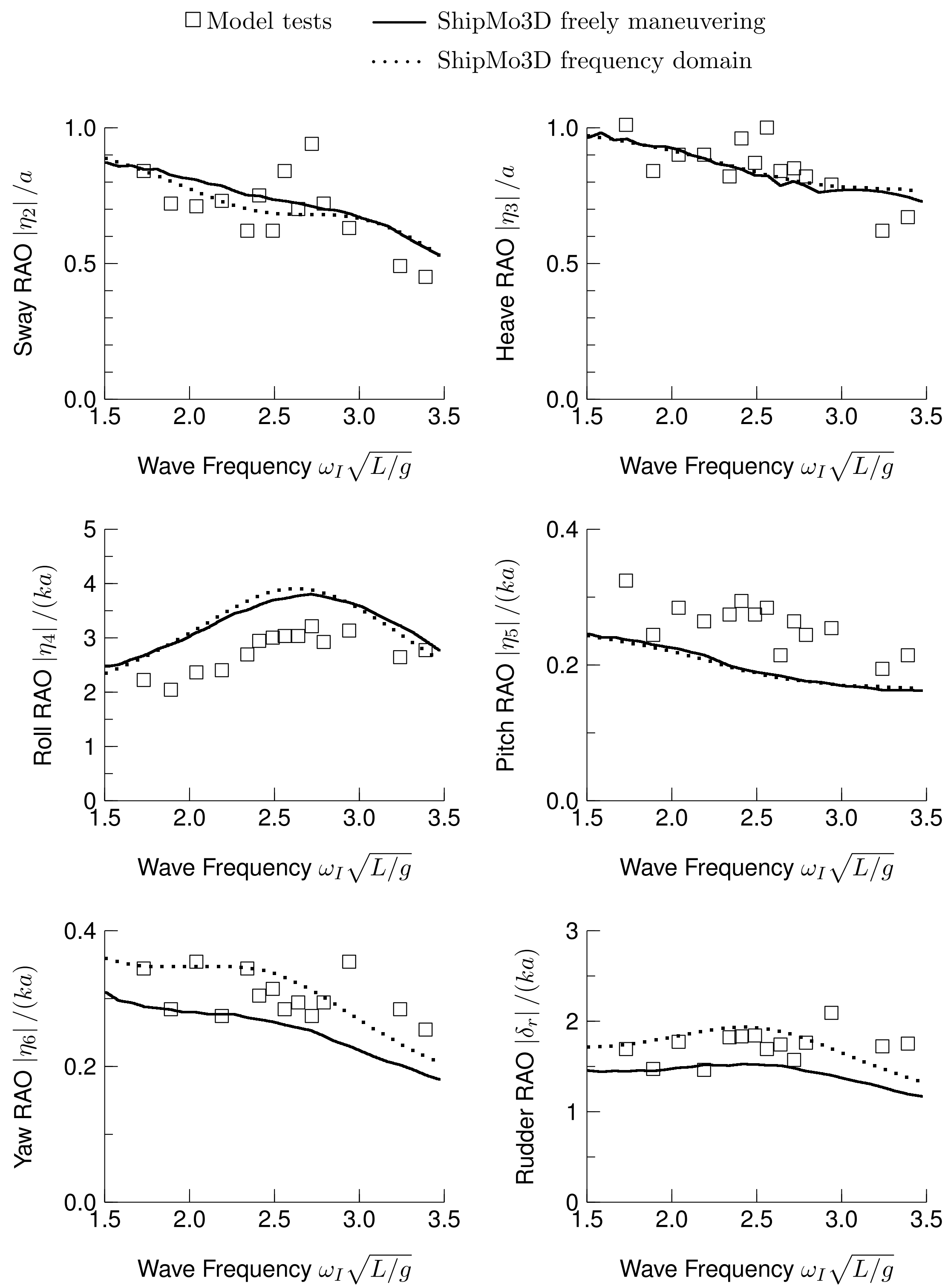

Figure 13: *RAOs for Steered Warship, Stern Quartering Seas at 75 degrees, Froude Number 0.36*

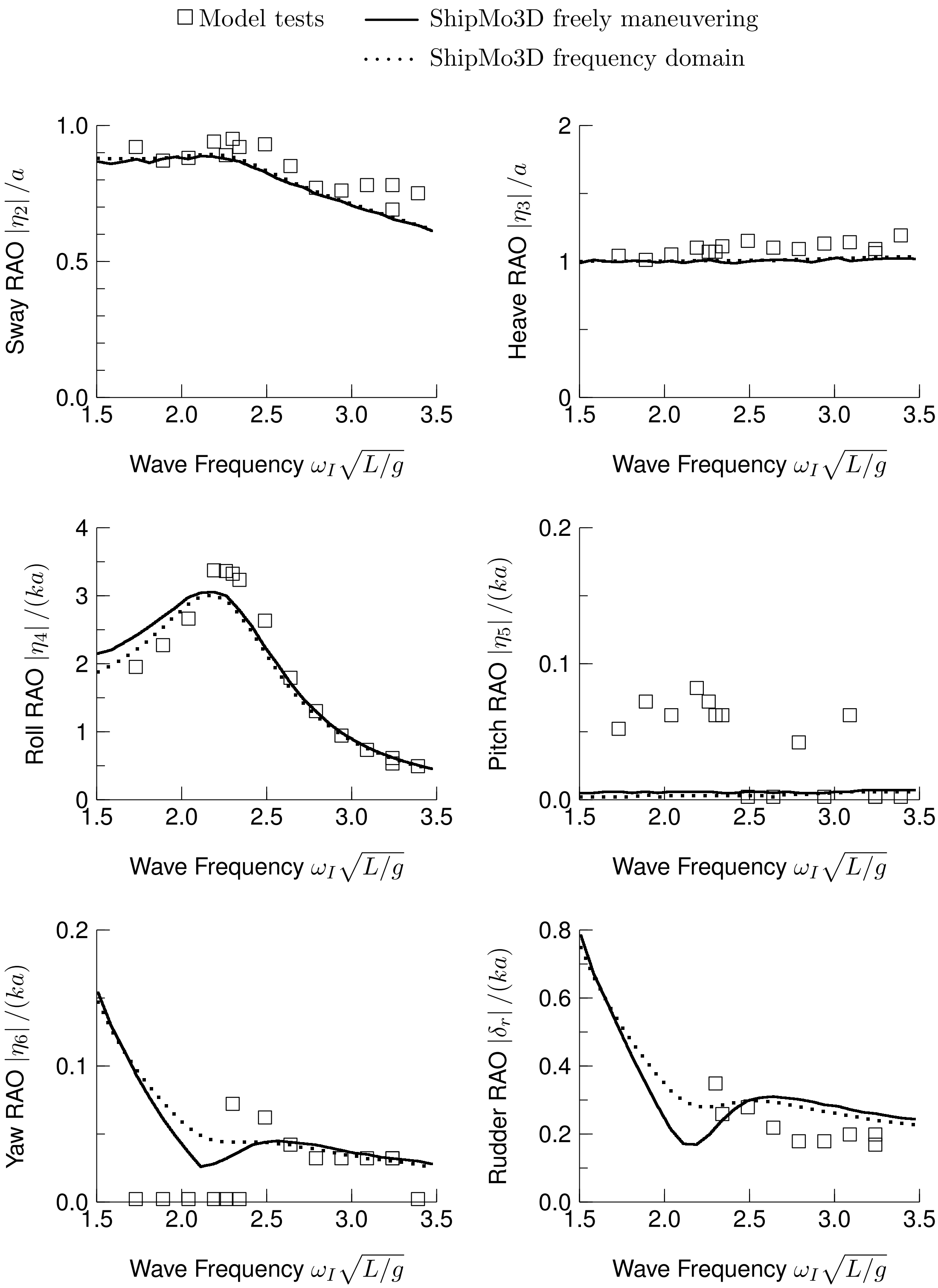

Figure 14: *RAOs for Steered Warship, Beam Seas at 90 degrees, Froude Number 0.18*

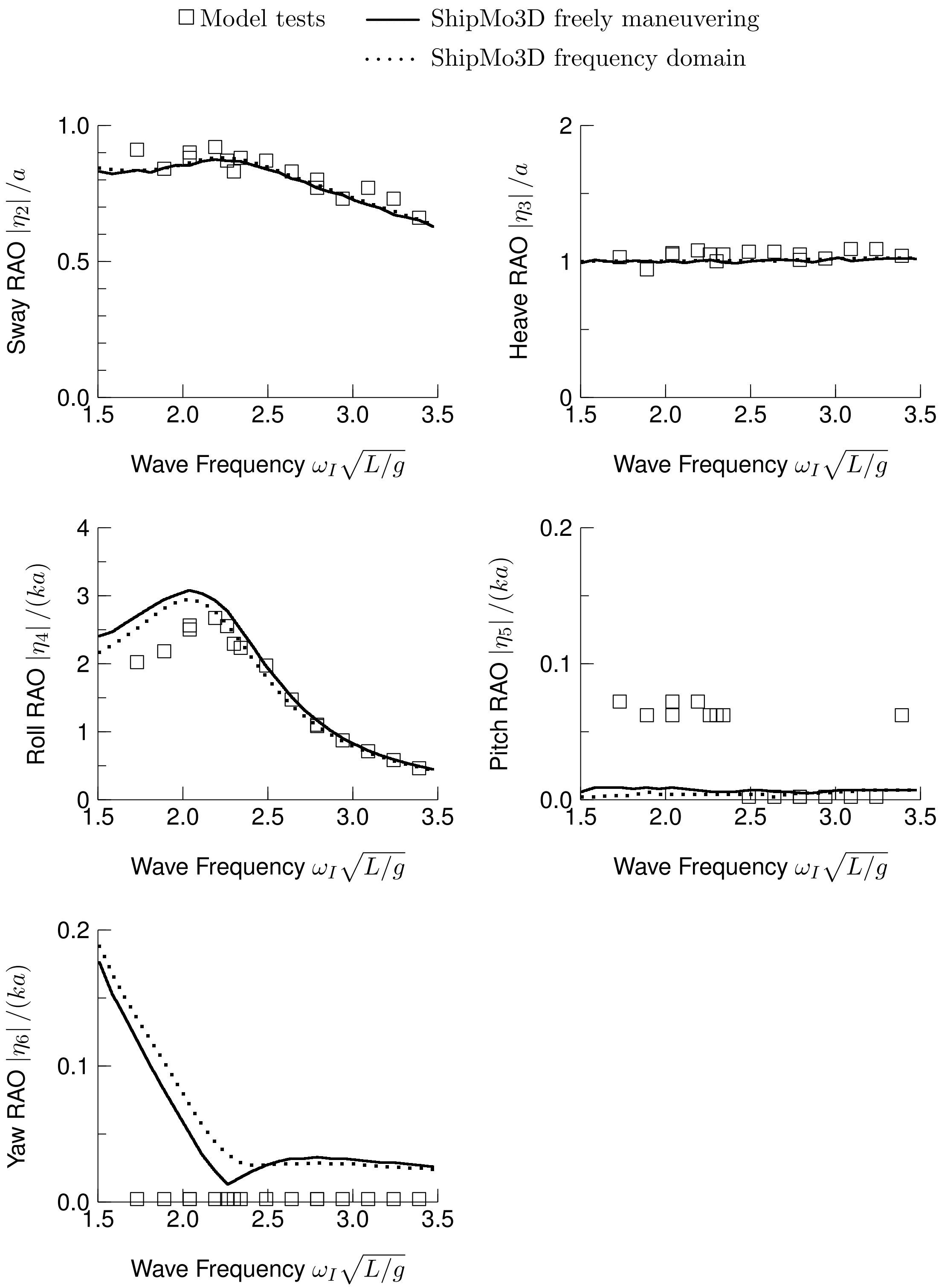

Figure 15: *RAOs for Steered Warship, Beam Seas at 90 degrees, Froude Number 0.28*

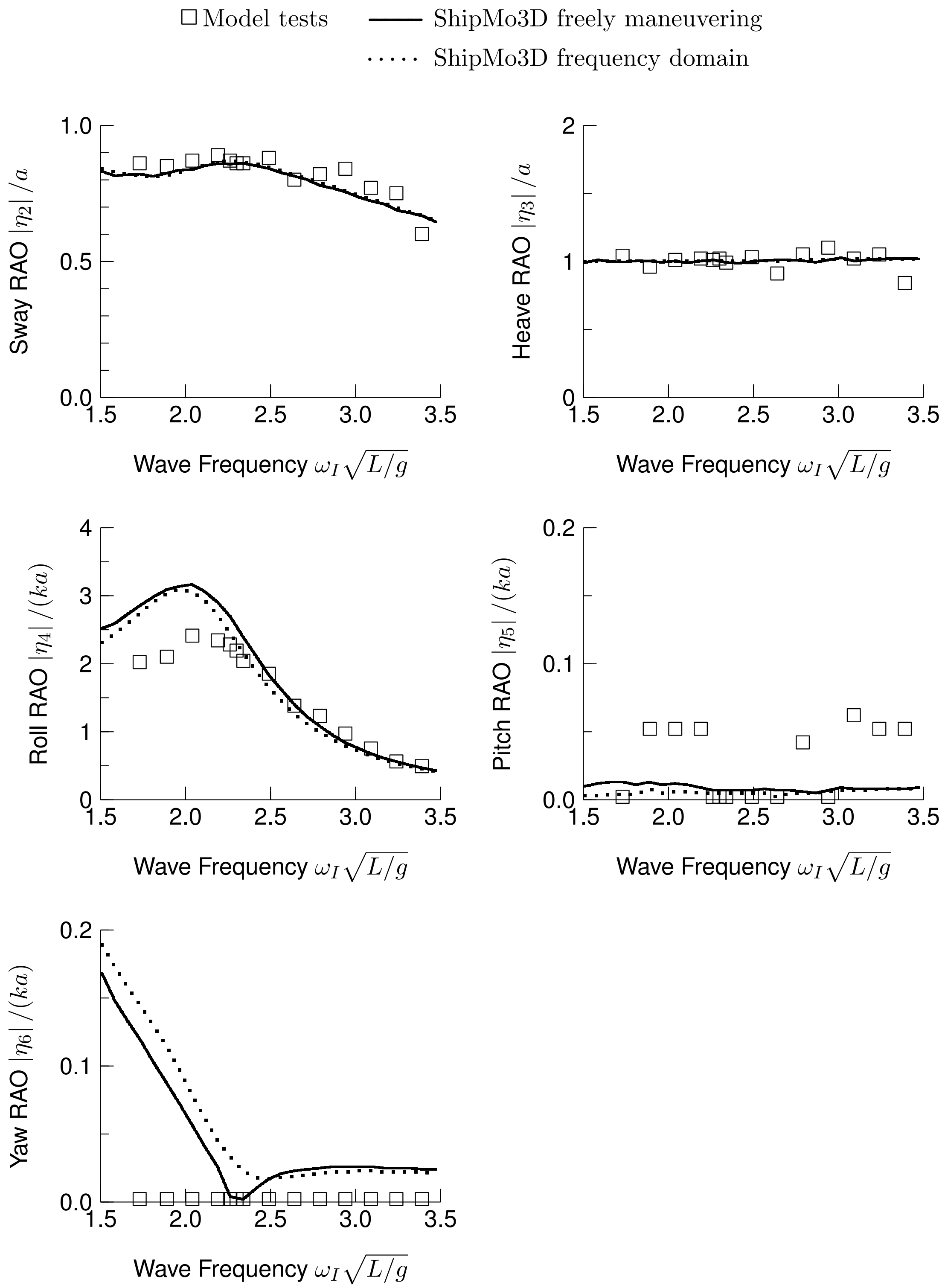

Figure 16: *RAOs for Steered Warship, Beam Seas at 90 degrees, Froude Number 0.36*

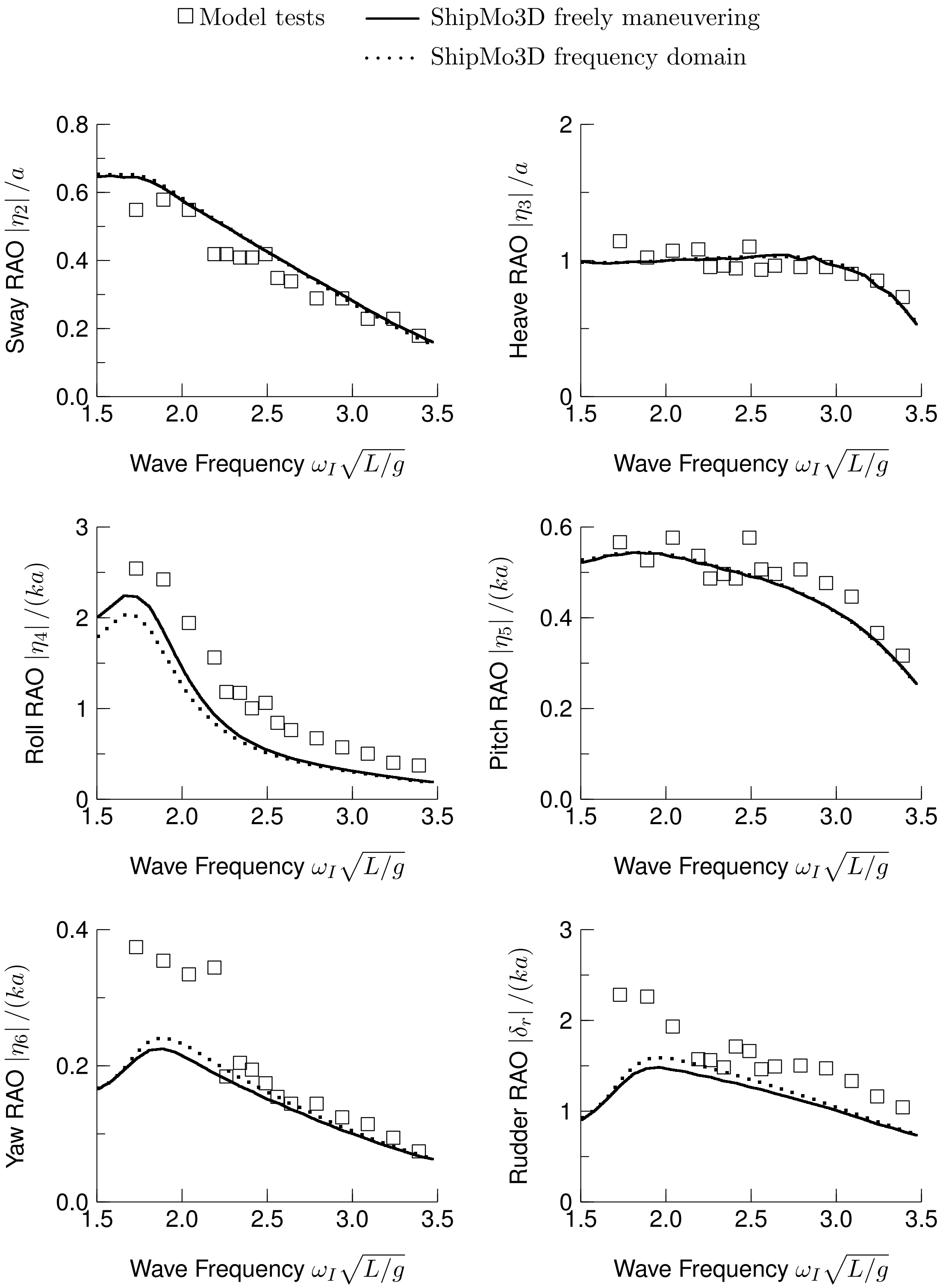

Figure 17: *RAOs for Steered Warship, Bow Quartering Seas at 120 degrees, Froude Number 0.27*

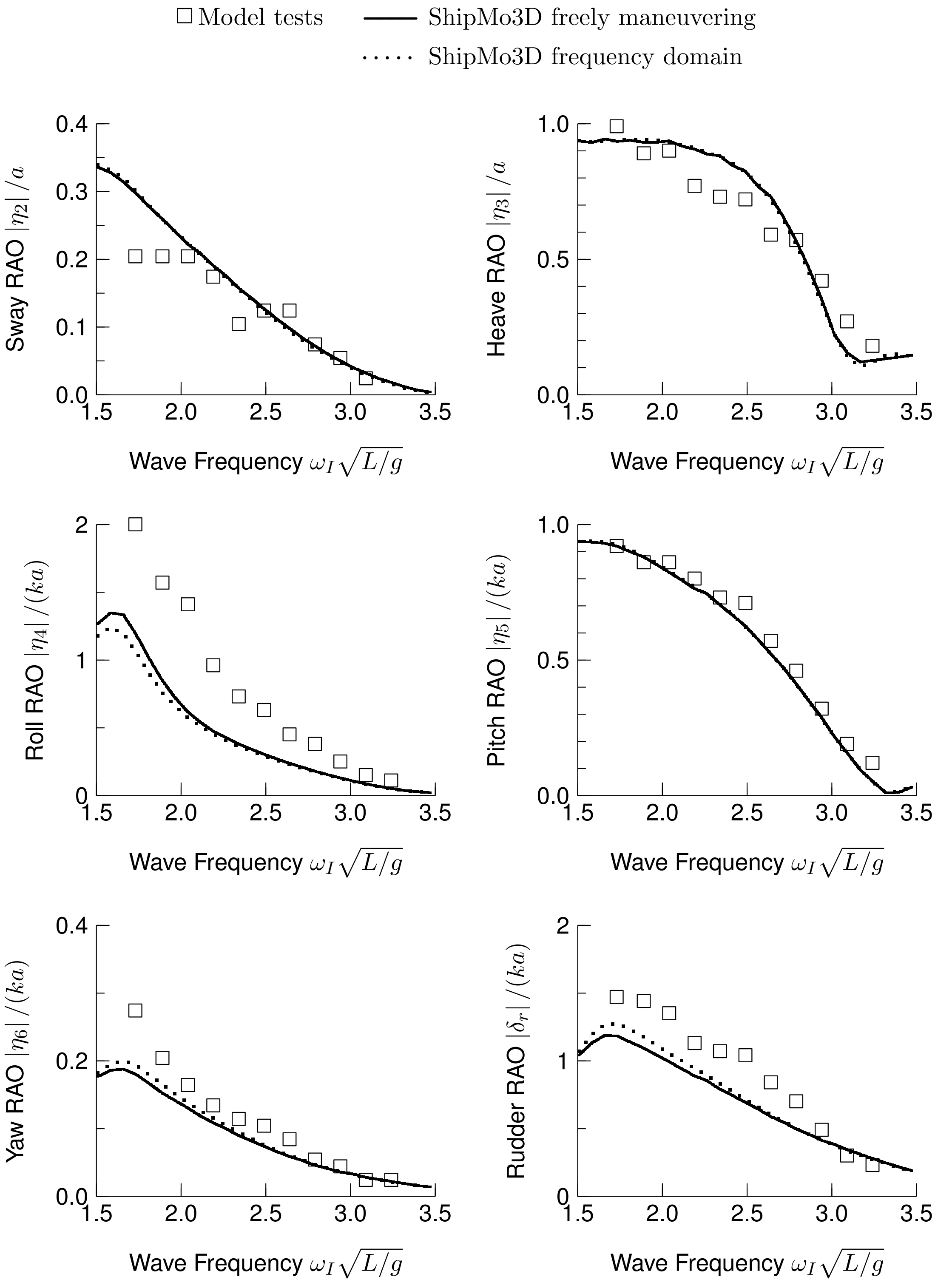

Figure 18: *RAOs for Steered Warship, Bow Quartering Seas at 150 degrees, Froude Number 0.26*

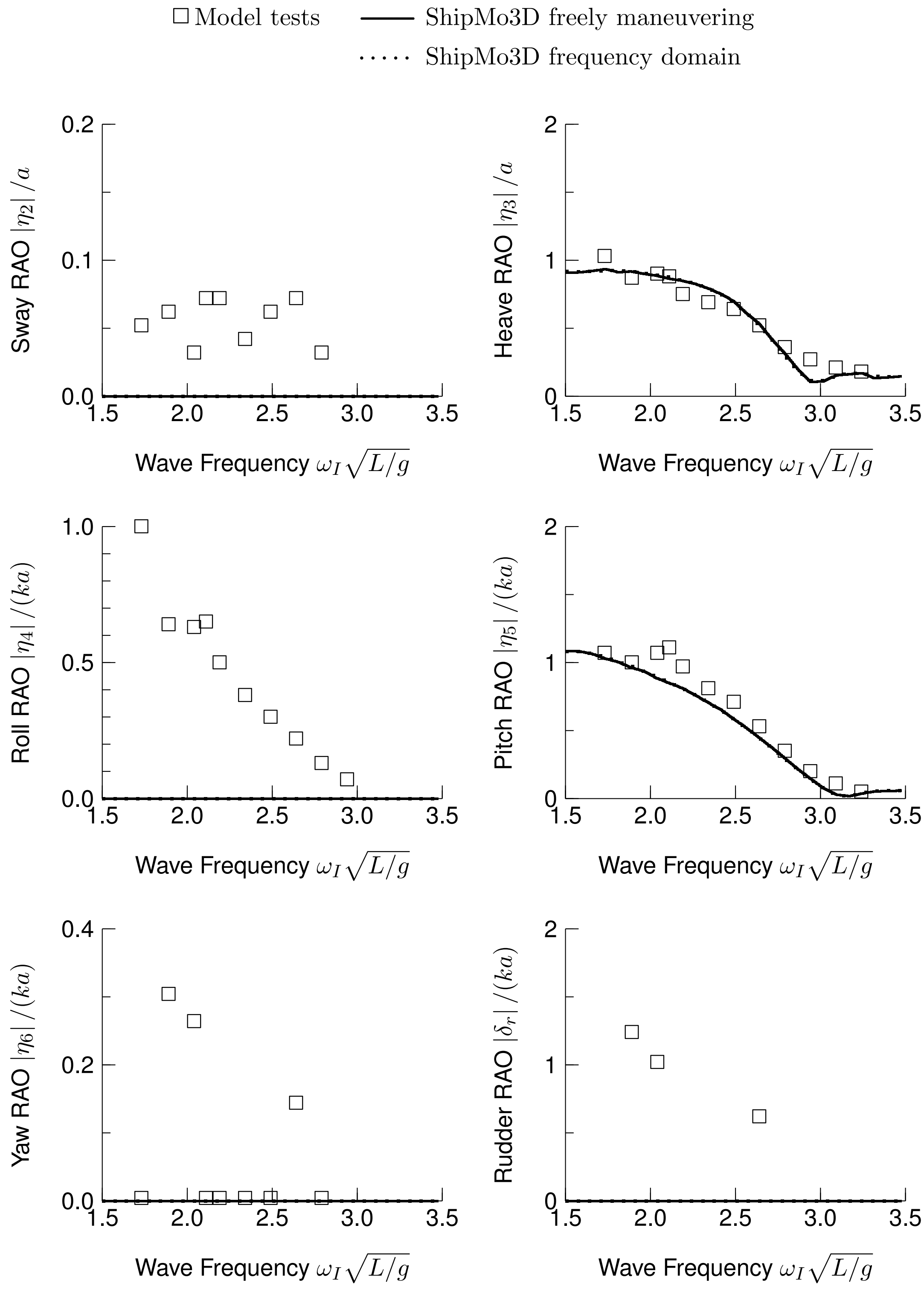

Figure 19: *RAOs for Steered Warship, Head Seas at 180 degrees, Froude Number 0.26*

2.4 Comparisons of Haslar Steered Warship Model Responses in a Random Seaway based on Experimental and Predicted Response Amplitude Operators

When considering validation of ship motion predictions in the context of engineering applications, the accuracy of motion predictions in random seaways is of great interest. Consequently, experimental and predicted RAOs for the steered warship model have been used to evaluate motions in a random seaway. For these computations, the size of the model has been scaled up by a factor of 20, giving a full-scale ship length of 112 m. The random seaway has been represented using a Bretschneider spectrum for sea state 6, with a significant wave height of 5.0 m and a peak wave period of 12.4 m. For evaluation of response spectral moments, a wave frequency integration range from 0.45 to 1.03 rad/s has been used. To ensure consistency between integration of response spectra from predicted and experimental RAOs, the same wave frequencies have been used during integration, with interpolation and extrapolation of experimental RAOs as required.

Tables 7 to 11 show RMS motions and zero-crossing periods in sea state 6 based on experimental and predicted RAOs. The predicted RAOs are based on ShipMo3D frequency domain computations using SM3DSeakeepRegular. For each mode, results are not included for relative sea direcitons at which responses are very small (i.e., relative sea directions of 0 and 180 degrees for sway, roll, and yaw, and a relative sea direction of 90 degrees for pitch and yaw). The results show very good agreement between motions from predicted and experimental RAOs. Zero-crossing periods from predicted and experimental RAOs are typically within 5 percent. For RMS sway and heave, values from predicted and experimental RAOs are typically within 5 percent. Differences in RMS motions for roll, pitch, and yaw are typically within 20 percent.

Table 7: *Sway RMS Motions and Zero-Crossing Periods for Steered Warship in Sea State 6*

Speed	Rel sea dir.	RMS (m)		T_z (s)	
(knots)	(deg)	Experiments	ShipMo3D	Experiments	ShipMo3D
11.6	30	0.25	0.28	10.12	11.04
17.3	30	0.73	0.59	7.96	8.11
23.8	30	2.13	2.34	8.45	7.74
11.6	60	0.76	0.72	10.01	10.45
17.3	60	0.70	0.62	10.38	11.17
23.1	60	0.74	0.82	8.19	10.12
11.6	75	0.93	0.92	10.00	10.03
18.0	75	0.91	0.87	9.94	9.95
23.1	75	0.82	0.86	10.11	10.15
11.6	90	0.98	0.95	9.92	10.00
18.0	90	0.96	0.93	9.95	9.88
23.1	90	0.94	0.92	9.86	9.83
17.3	120	0.53	0.61	10.68	10.76
16.7	150	0.19	0.26	10.99	11.47

Statistics for ratios of predicted/experimental		
Mean	1.03	1.03
Deviation	0.13	0.07

Table 8: *Heave RMS Motions and Zero-Crossing Periods for Steered Warship in Sea State 6*

Speed (knots)	Rel sea dir. (deg)	RMS (m) Experiments	RMS (m) ShipMo3D	T_z (s) Experiments	T_z (s) ShipMo3D
18.0	0	0.54	0.57	11.67	11.77
23.8	0	0.50	0.56	11.26	11.67
11.6	30	0.66	0.66	11.36	11.52
17.3	30	0.67	0.64	11.37	11.57
23.8	30	0.63	0.62	11.50	11.57
11.6	60	0.88	0.89	10.43	10.60
17.3	60	0.89	0.85	10.65	10.80
23.1	60	0.86	0.82	10.60	10.96
11.6	75	1.03	1.04	10.00	9.97
18.0	75	1.00	1.02	9.94	9.99
23.1	75	1.00	1.00	10.08	10.01
11.6	90	1.17	1.12	9.57	9.68
18.0	90	1.13	1.12	9.64	9.69
23.1	90	1.11	1.12	9.75	9.70
17.3	120	1.14	1.11	10.06	9.80
16.7	150	0.91	0.96	10.76	10.55
16.7	180	0.90	0.90	11.00	10.79

Statistics for ratios of predicted/experimental	RMS (m)	T_z (s)
Mean	1.00	1.01
Deviation	0.05	0.02

Table 9: *Roll RMS Motions and Zero-Crossing Periods for Steered Warship in Sea State 6*

Speed (knots)	Rel sea dir. (deg)	RMS (deg) Experiments	RMS (deg) ShipMo3D	T_z (s) Experiments	T_z (s) ShipMo3D
11.6	30	2.41	2.84	8.82	8.99
17.3	30	3.49	3.02	9.09	9.39
23.8	30	3.70	2.64	9.71	9.80
11.6	60	7.41	7.22	7.74	7.99
17.3	60	5.87	8.10	8.30	7.99
23.1	60	7.46	7.40	8.28	8.30
11.6	75	8.08	7.20	8.22	8.59
18.0	75	7.86	8.70	7.92	8.34
23.1	75	8.07	10.19	7.89	8.05
11.6	90	6.16	5.88	9.30	9.41
18.0	90	5.15	5.65	9.48	9.67
23.1	90	4.89	5.67	9.44	9.85
17.3	120	4.05	2.66	10.44	10.73
16.7	150	2.84	1.41	10.91	11.00

Statistics for ratios of predicted/experimental	RMS (deg)	T_z (s)
Mean	0.98	1.02
Deviation	0.23	0.02

Table 10: *Pitch RMS Motions and Zero-Crossing Periods for Steered Warship in Sea State 6*

Speed	Rel sea dir.	RMS (deg)		T_z (s)	
(knots)	(deg)	Experiments	ShipMo3D	Experiments	ShipMo3D
18.0	0	1.13	1.16	10.82	10.52
23.8	0	1.01	1.20	11.12	10.44
11.6	30	1.19	1.15	9.95	10.31
17.3	30	1.28	1.13	10.36	10.25
23.8	30	1.15	1.14	10.63	10.08
11.6	60	1.20	0.96	8.85	9.14
17.3	60	1.16	0.87	9.05	9.49
23.1	60	1.14	0.83	9.08	9.54
11.6	75	0.80	0.67	8.40	8.30
18.0	75	0.79	0.62	8.37	8.39
23.1	75	0.77	0.58	8.52	8.47
17.3	120	1.47	1.40	8.56	8.61
16.7	150	1.87	1.79	9.69	9.78
16.7	180	2.07	1.85	10.07	10.15

Statistics for ratios of predicted/experimental		
Mean	0.89	1.00
Deviation	0.13	0.03

Table 11: *Yaw RMS Motions and Zero-Crossing Periods for Steered Warship in Sea State 6*

Speed	Rel sea dir.	RMS (deg)		T_z (s)	
(knots)	(deg)	Experiments	ShipMo3D	Experiments	ShipMo3D
11.6	30	1.35	1.32	9.28	9.34
17.3	30	2.33	1.54	8.71	8.91
23.8	30	2.40	1.30	8.95	8.93
11.6	60	1.30	1.37	8.96	8.87
17.3	60	1.72	1.69	8.67	8.38
23.1	60	3.07	1.61	8.03	8.21
11.6	75	0.80	0.74	8.28	9.14
18.0	75	0.88	0.88	8.10	8.93
23.1	75	0.92	0.93	8.26	8.54
17.3	120	0.68	0.49	9.95	9.23
16.7	150	0.38	0.30	10.71	10.36

Statistics for ratios of predicted/experimental		
Mean	0.83	1.01
Deviation	0.19	0.05

3 Wave-Induced Motions of the Naval Destroyer HMCS NIPIGON from Sea Trials

Although seakeeping model tests likely experience only minimal scale effects for reasonably sized models (e.g., model scales greater than 1/30 for naval frigates and destroyers), full-scale sea trials can provide further confidence in predictions of ship motions. Reliable measurements of both ship motions and wave conditions are essential for sea trial data to be used for validation of ship motion predictions. DRDC Atlantic has conducted many sea trials for measuring ship motions, with structural load measurements often being included in sea trials. A comprehensive sea trial was conducted in December 1997 to measure ship motions and sea loads for HMCS NIPIGON [14]. This section gives comparisons of measured motions with ShipMo3D predictions.

3.1 HMCS NIPIGON

.

HMCS NIPIGON (Figure 20) was the last steam-driven destroyer in the Canadian Fleet. Table 12 gives particular for NIPIGON and Figure 21 gives a body plan. NIPIGON appendages include 2 rudders, 2 outer propeller shaft brackets, 2 inner propeller shaft brackets, 2 bilge keels, and a skeg, with dimensions as given in Tables 13 to 16.

Table 12: *Main Particulars for HMCS NIPIGON*

Length, L	108.4 m
Beam, B	12.8 m
Midships draft, T_{mid}	4.3 m
Trim by stern, t_{stern}	0.5 m
Displacement, $\triangle$	3027 tonnes
Vertical centre of gravity, $\overline{KG}$	5.1 m
Metacentric height, $\overline{GM}_{fluid}$	1.2 m
Roll radius of gyration, r_{xx}	5.6 m
Pitch radius of gyration, r_{yy}	27.1 m
Natural roll period	10.6 s

Figure 20: *HMCS NIPIGON*

Table 13: *Bilge Keel Dimensions for HMCS NIPIGON*

Station (20 at AP)	8.82	10	11	12	13	13.79
Span (m)	0.610	0.610	0.610	0.610	0.610	0.610
Root lateral offset (m)	5.775	5.734	5.623	5.559	5.553	5.578
Root above baseline (m)	2.207	1.867	1.848	1.959	2.203	2.448
Dihedral angle (deg, port side)	-45	-45	-45	-45	-45	-45

Table 14: *Skeg Dimensions for HMCS NIPIGON*

Station (20 at AP)	14	15	16	16.5
Span (m)	0.067	0.293	0.823	1.236
Root above baseline (m)	0.067	0.293	0.823	1.236

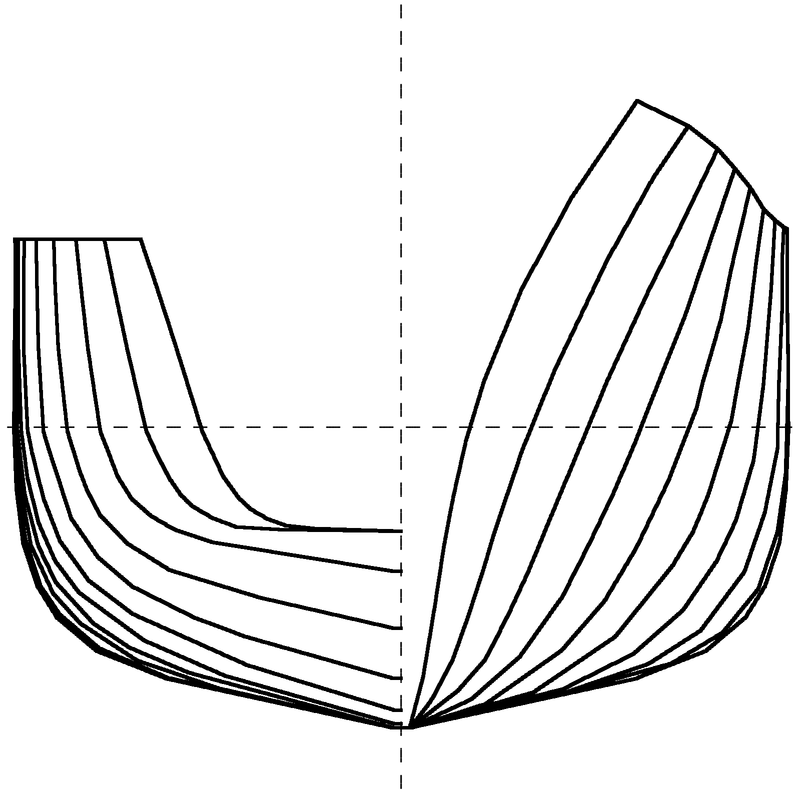

Figure 21: *Body Plan for HMCS NIPIGON*

Table 15: *Propeller Shaft Bracket Dimensions for HMCS NIPIGON*

	Inner brackets	Outer bracket
Station (20 at AP)	18.3	18.3
Span (m)	2.240	2.256
Root chord (m)	0.800	0.800
Tip chord (m)	0.800	0.800
Root lateral offset (m)	1.158	3.109
Root above baseline (m)	2.957	3.200
Dihedral angle (deg, port side)	-64.2	-99.5

Table 16: *Rudder Dimensions for HMCS NIPIGON*

Station (20 at AP)	19.3
Span (m)	3.023
Root chord (m)	2.286
Tip chord (m)	1.886
Root lateral offset (m)	1.981
Root above baseline (m)	3.197
Dihedral angle (deg, port side)	-90.0

3.2 Conditions for HMCS NIPIGON Sea Trial

During the December 1997 sea trial, a series of 71 trial runs of 20 to 30 minute duration was undertaken at two nominal ship speeds in head, bow, beam, stern quartering and following seas. Data were collected in higher sea states (4, 5 and 6) for three days over December 2, 3 and 4th and for four days at lower sea states (2 and 3) over December 8 to 11th. The 'low' ship speed was about 8 knots and 'high' ship speed was between 14 and 18 knots depending on what speed the ship could maintain in the given sea state. Speed was limited due to the loss of one of the two ship boilers on the first day of the trial.

Trial instrumentation included a ship motions package, a wave buoy, a TSK over-the-bow wave height meter, an array of 24 pressure transducers outfitted in the hull below the waterline, 15 single strain gauges, and 4 rosette strain gauges. Wave data were collected for 20 minutes out of every hour from the wave buoy. An Endeco type 1156 directional wave buoy was used for the first 3 days of the trial, and a type 956 buoy was used for the last 4 days. The main data acquisition system was a PC-based LabVIEW system. All sixty instrumentation channels were digitally sampled at 20 Hz. Time histories, statistical distributions and minimum and maximum values were determined and recorded.

For validation of ShipMo3D, runs from the sea trial were selected which satisfy the following criteria:

- the significant wave height H_s was greater than 3 m,
- there was a clear dominant wave direction and minimal directional wave spreading,
- the nominal relative wave direction was oblique (bow quartering, beam, or stern quartering seas).

Table 17 gives a summary of the runs selected for the present study, with T_z denoting zero-crossing wave period.

Table 17: *HMCS NIPIGON Trial Runs for ShipMo3D Validation*

Run	Speed (kt)	H_s (m)	T_z (s)	Wave direction (from, deg)		Ship heading (to, deg)	Relative sea direction
				Mean	Deviation		
203	8	3.73	7.73	218	39	265	Bow quarter
204	8	3.67	7.21	225	39	85	Stern quarter
206	16	3.89	7.39	228	25	355	Stern quarter
209	13	4.75	8.07	224	33	265	Bow quarter
210	15	4.75	8.07	224	33	85	Stern quarter
303	8	5.82	9.45	274	41	310	Bow quarter
304	8	5.57	8.81	272	39	120	Stern quarter
305	8	5.57	8.81	272	39	220	Bow quarter
306	8	5.16	8.66	266	45	50	Stern quarter
309	14	5.39	8.95	279	32	315	Bow quarter
310	14	5.44	8.73	269	43	135	Stern quarter
403	8	5.01	9.34	244	40	290	Bow quarter
404	8	4.90	9.60	238	47	110	Stern quarter
409	16	4.52	8.37	238	50	285	Bow quarter
410	16	4.52	8.37	238	50	105	Stern quarter
413	8	4.98	8.86	245	40	330	Beam

3.3 ShipMo3D Input Files for HMCS NIPIGON Sea Trials

Annex B gives ShipMo3D input files for the HMCS NIPIGON. For brevity, this report doesn't give ShipMo3D output files.

Annex B.1 gives the SM3DPanelHull input file for panelling the hull. This file uses the file *nipigonPatch.inp* (Annex B.2), which has required hull geometric data. SM3DPanelHull models the hull as the following surfaces represented by bidirectional B-splines:

- forward portion of hull from station -1.0 to 0.0,
- forward portion of hull from station 0.0 to 1.0, excluding the keel,
- forward portion of keel from station 0.0 to 1.0,

- main keel from station 1.0 to 20.0,
- main hull from station 1.0 to 20.0,
- transom,
- forward half of deck, stations -1.0 to 10.0,
- aft half of deck, stations 10.0 to 20.0.

Annex B.3 gives the SM3DRadDif input file for radiation and diffraction computations. SM3DRadDif was run more than once such that appropriate limits on condition numbers could be selected for suppression of irregular frequencies.

Annex B.4 gives the SM3DBuildShip input file for creating a time domain model of the ship. A very similar input file was used for creating a frequency domain model of the ship, with changes made to the *shipType* option and the name of the ship model output file specified in the *shipDBFileName* record. Figure 22 shows graphical output of the ship model from SM3DBuildShip. The wetted portion of the hull is shown in yellow and dry portion of the hull is shown in green. The ship appendages are shown in red, including the rudders, propeller shaft brackets, and bilge keels. The propellers are shown in blue.

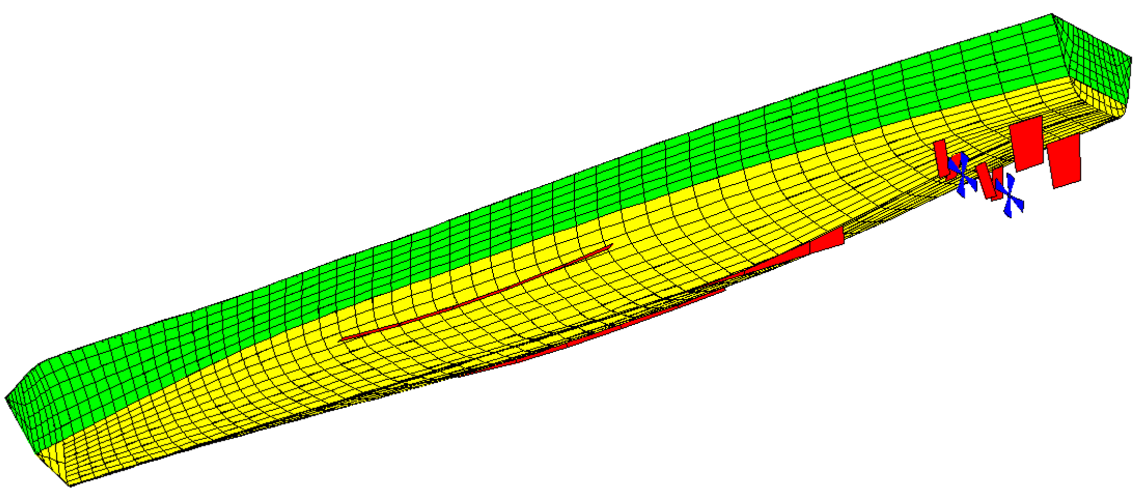

Figure 22: *ShipMo3D Model for HMCS NIPIGON*

Due to lack of available data, some of the input parameters for NIPIGON had to be estimated. Hull resistance was estimated using the method of Holtrop and Mennen [11], which is available as an option in SM3DBuildShip. The variation of propeller thrust coefficient with advance ratio was based on a representative curve from Reference 12. For each rudder, the rudder-propeller coefficient associated with the propeller

on the same side of the ship was given a value of 0.9, based on the assumption that 90 percent of the rudder area was within the propeller slipstream. The flow straightening coefficient for each rudder was estimated to be 0.7 based on Equation (3). For each ship speed used for sea trials, the associated propeller RPM settings for calm water were determined using SM3DBuildShip, which uses an iterative process.

No rudder deflection or autopilot data were available for NIPIGON during the sea trial. Previous validation studies of SHIPMO7 and ShipMo3D [10, 15] assumed zero rudder deflections for NIPIGON during sea trials. For the present study, it was decided it would be more realistic to use rudder autopilots with relatively low gains and low natural frequency for modelling the coursekeeping during the sea trial. Table 18 gives the assumed rudder autopilot settings that were used for ShipMo3D computations.

Table 18: *Assumed Rudder Control Properties for HMCS NIPIGON During Sea Trial*

Maximum deflection angle δ_{max}^{rudder}	35 deg
Maximum deflection rate $\dot{\delta}_{max}^{rudder}$	3 deg/s
Deflection natural frequency ω_δ	0.2 rad/s
Deflection damping ratio ζ_δ	0.85
Yaw displacement gain $k_{\delta 6}^{P}$	-2.0
Yaw velocity gain $k_{\delta 6}^{D}$	-4.0 s

Annex B.5 gives the SM3DBuildSeaway input file for building a random seaway based on the directional spectrum for run 203 measured by the Endeco wave buoy. The input file specifies that SM3DBuildSeaway read input data from the output file produced by the Endeco wave buoy. SM3DBuildSeaway then produces a directional seaway with wave component amplitudes based on spectral densities and randomly generated phases.

Annex B.6 gives a SM3DFreeMo input file for predicting motions of NIPIGON freely maneuvering in the time domain. The sample input file is for run 203, with similar input files being created for other trial runs.

Annex B.7 gives the SM3DSeakeepSeaway input file for predicting motions in the frequency domain for run 203 using the measured multidirectional wave spectrum. Similarly, Annex B.8 gives the SM3DSeakeepRandom input file for predicting motions in the frequency domain for the conditions of run 203 approximated by long-crested random seas.

3.4 Comparisons of Numerical Predictions and Experimental Results for HMCS NIPIGON Sea Trials

Predicted and computed motions for HMCS NIPIGON are given in Tables 19 to 26 and Figures 23 to 25. When the directionality of the seaway is modelled (all computations except for frequency domain unidirectional), predicted RMS motions and zero-crossing periods are typically within 10 percent of observed values, with the exception of RMS roll, which is typically within 30 percent of observed values. These results are typical of computations of ship motions in waves (e.g., Reference 15), which tend to be more accurate for vertical plane motions than for lateral plane motions.

The linear time domain predictions and frequency domain predictions for directional seas have excellent agreement, suggesting the time and frequency domain ShipMo3D implementations are consistent. The frequency domain predictions with directional and unidirectional seas give similar results, with the directional sea predictions giving better agreement with observed values due to the more accurate modelling of the actual seaways.

Comparisons between linear and nonlinear time domain predictions provide further insight. The heave and pitch predictions show little difference between linear and nonlinear predictions. For roll, the nonlinear predictions are an average of 5 percent greater than the linear time domain predictions. This difference prompted further examination of results, including yaw motion predictions. Tables 25 and 26 indicate that predicted yaw motions can be quite sensitive to the inclusion of nonlinear buoyancy and incident wave forces. This sensitivity is likely due to variability of sectional drafts with relative vertical motions. The dependence of predicted yaw on nonlinear effects will influence rudder deflections and roll forces.

Table 19: *Measured and Predicted RMS Heave for HMCS NIPIGON*

Run	Speed (knots)	Relative Sea dir.	Observed	Time domain Nonlinear	Time domain Linear	Frequency domain Direct.	Frequency domain Unidirect.
203	8	Bow quarter	0.70	0.60	0.63	0.65	0.64
204	8	Stern quarter	0.55	0.50	0.47	0.47	0.41
206	16	Stern quarter	0.76	0.58	0.56	0.58	0.46
209	13	Bow quarter	0.84	0.94	0.94	0.96	0.91
210	15	Stern quarter	0.89	0.67	0.68	0.67	0.54
303	8	Bow quarter	1.38	1.02	1.04	1.10	1.11
304	8	Stern quarter	1.02	0.90	0.87	0.91	0.83
305	8	Bow quarter	0.98	1.17	1.24	1.20	1.13
306	8	Stern quarter	0.81	0.86	0.94	0.95	0.77
309	14	Bow quarter	1.33	1.15	1.13	1.11	1.10
310	14	Stern quarter	0.97	0.95	0.93	0.89	0.87
403	8	Bow quarter	1.15	0.98	0.98	1.00	1.01
404	8	Stern quarter	0.88	0.88	0.85	0.92	0.95
409	16	Bow quarter	1.13	0.90	0.94	0.94	1.02
410	16	Stern quarter	0.78	0.69	0.73	0.72	0.69
413	8	Beam	1.09	1.21	1.17	1.15	1.28
		Predicted/observed					
		Mean		0.92	0.93	0.94	0.90
		Deviation		0.14	0.15	0.14	0.16

Table 20: *Measured and Predicted Heave Zero-Crossing Period for HMCS NIPIGON*

Run	Speed (knots)	Relative Sea dir.	Observed	Time domain Nonlinear	Time domain Linear	Frequency domain Direct.	Frequency domain Unidirect.
203	8	Bow quarter	8.1	8.3	8.3	8.3	7.9
204	8	Stern quarter	9.3	10.5	10.3	10.2	12.6
206	16	Stern quarter	11.8	10.3	10.2	10.2	14.3
209	13	Bow quarter	7.3	7.3	6.9	6.9	6.7
210	15	Stern quarter	11.7	11.5	11.9	11.7	16.1
303	8	Bow quarter	9.7	9.7	9.9	9.7	9.3
304	8	Stern quarter	12.2	13.2	13.4	13.3	15.0
305	8	Bow quarter	8.6	8.8	8.8	8.5	8.9
306	8	Stern quarter	11.1	10.6	10.9	10.7	14.2
309	14	Bow quarter	9.6	8.4	8.1	7.9	7.6
310	14	Stern quarter	11.7	13.2	13.2	13.1	16.3
403	8	Bow quarter	10.0	9.6	9.4	9.4	9.3
404	8	Stern quarter	11.2	12.5	12.6	12.3	13.4
409	16	Bow quarter	8.3	7.3	7.1	7.2	6.9
410	16	Stern quarter	11.3	11.6	11.9	11.8	16.8
413	8	Beam	10.2	8.9	9.0	8.7	8.5
		Predicted/observed					
		Mean		0.99	0.99	0.98	1.11
		Deviation		0.09	0.09	0.09	0.22

Table 21: Measured and Predicted RMS Roll for HMCS NIPIGON

Run	Speed (knots)	Relative Sea dir.	Observed	Time domain Nonlinear	Time domain Linear	Frequency domain Direct.	Frequency domain Unidirect.
203	8	Bow quarter	2.83	3.82	3.62	3.57	3.01
204	8	Stern quarter	3.97	4.84	4.56	4.81	5.05
206	16	Stern quarter	4.25	7.21	7.08	6.54	6.48
209	13	Bow quarter	2.64	3.39	2.82	2.79	1.70
210	15	Stern quarter	4.98	6.57	6.57	6.56	3.86
303	8	Bow quarter	4.95	5.13	5.34	5.96	5.92
304	8	Stern quarter	6.16	5.90	4.97	5.62	5.12
305	8	Bow quarter	3.18	6.46	5.86	5.94	6.24
306	8	Stern quarter	4.46	6.51	6.74	7.01	6.13
309	14	Bow quarter	3.93	4.75	4.11	3.88	3.26
310	14	Stern quarter	5.41	6.52	6.20	5.26	5.44
403	8	Bow quarter	3.95	5.56	4.62	5.25	5.89
404	8	Stern quarter	4.26	5.77	5.35	5.44	6.84
409	16	Bow quarter	2.63	3.90	3.48	3.51	3.03
410	16	Stern quarter	3.75	4.37	4.45	4.11	4.32
413	8	Beam	4.24	7.62	7.08	6.92	7.71
		Predicted/observed					
		Mean		1.37	1.28	1.29	1.23
		Deviation		0.27	0.26	0.25	0.37

Table 22: *Measured and Predicted Roll Zero-Crossing Period for HMCS NIPIGON*

Run	Speed (knots)	Relative Sea dir.	Observed	Time domain Nonlinear	Time domain Linear	Frequency domain Direct.	Frequency domain Unidirect.
203	8	Bow quarter	9.2	9.8	10.0	9.9	9.4
204	8	Stern quarter	10.2	10.7	11.0	10.7	10.7
206	16	Stern quarter	12.3	10.6	10.7	11.1	13.1
209	13	Bow quarter	8.4	9.1	9.0	9.0	7.6
210	15	Stern quarter	12.3	11.2	11.4	11.7	15.5
303	8	Bow quarter	9.5	10.4	10.9	10.7	10.3
304	8	Stern quarter	11.0	11.2	11.0	11.0	11.1
305	8	Bow quarter	8.8	10.1	10.1	10.3	10.3
306	8	Stern quarter	10.7	10.7	10.8	10.6	11.1
309	14	Bow quarter	9.1	9.7	9.9	10.0	9.7
310	14	Stern quarter	11.5	11.4	11.5	11.8	13.7
403	8	Bow quarter	10.0	10.3	10.4	10.5	10.4
404	8	Stern quarter	10.7	10.5	11.0	10.9	11.0
409	16	Bow quarter	9.5	10.3	10.4	10.3	9.4
410	16	Stern quarter	12.1	11.7	12.1	12.4	14.9
413	8	Beam	10.0	10.1	10.3	10.4	10.5
		Predicted/observed					
		Mean		1.02	1.04	1.04	1.08
		Deviation		0.07	0.07	0.06	0.09

Table 23: *Measured and Predicted RMS Pitch for HMCS NIPIGON*

Run	Speed (knots)	Relative Sea dir.	Observed	Time domain Nonlinear	Time domain Linear	Frequency domain Direct.	Frequency domain Unidirect.
203	8	Bow quarter	1.03	1.12	1.03	1.19	1.43
204	8	Stern quarter	0.79	0.92	0.86	0.88	0.90
206	16	Stern quarter	1.00	0.89	0.85	0.90	0.87
209	13	Bow quarter	1.45	1.97	1.90	1.96	2.15
210	15	Stern quarter	1.08	1.15	1.15	1.10	1.16
303	8	Bow quarter	1.66	1.92	1.72	2.05	2.18
304	8	Stern quarter	1.51	1.34	1.15	1.30	1.42
305	8	Bow quarter	1.89	1.75	1.76	1.80	1.99
306	8	Stern quarter	1.44	1.13	1.26	1.29	1.36
309	14	Bow quarter	1.59	1.97	2.02	1.97	2.18
310	14	Stern quarter	1.21	1.26	1.17	1.22	1.24
403	8	Bow quarter	1.37	1.69	1.58	1.71	1.74
404	8	Stern quarter	1.08	1.29	1.25	1.25	1.20
409	16	Bow quarter	1.59	1.73	1.66	1.74	1.86
410	16	Stern quarter	1.04	1.02	1.05	1.07	1.00
413	8	Beam	1.10	1.24	1.21	1.27	0.46
		Predicted/observed					
		Mean		1.08	1.04	1.09	1.10
		Deviation		0.15	0.14	0.14	0.25

Table 24: *Measured and Predicted Pitch Zero-Crossing Period for HMCS NIPIGON*

Run	Speed (knots)	Relative Sea dir.	Observed	Time domain Nonlinear	Linear	Frequency domain Direct.	Unidirect.
203	8	Bow quarter	6.3	7.1	6.9	7.2	6.7
204	8	Stern quarter	7.9	9.9	10.1	9.8	11.4
206	16	Stern quarter	12.1	10.8	10.8	11.1	13.6
209	13	Bow quarter	5.8	6.4	6.2	6.2	6.2
210	15	Stern quarter	10.1	13.4	13.9	13.4	15.7
303	8	Bow quarter	7.3	7.9	7.5	7.8	7.7
304	8	Stern quarter	10.8	12.7	12.3	12.6	13.3
305	8	Bow quarter	7.3	7.2	7.1	6.9	6.8
306	8	Stern quarter	11.4	10.2	10.8	10.5	12.5
309	14	Bow quarter	6.7	6.8	6.2	6.3	6.3
310	14	Stern quarter	10.3	14.4	14.3	13.7	14.8
403	8	Bow quarter	7.7	7.5	7.3	7.5	7.5
404	8	Stern quarter	9.2	11.2	11.2	11.5	11.3
409	16	Bow quarter	6.5	6.2	5.7	5.9	5.9
410	16	Stern quarter	10.2	11.7	11.5	11.9	15.6
413	8	Beam	8.0	7.8	7.3	7.1	5.9
		Predicted/observed					
		Mean		1.10	1.08	1.08	1.15
		Deviation		0.15	0.16	0.15	0.23

Table 25: *Predicted RMS Yaw for HMCS NIPIGON*

Run	Speed (knots)	Relative sea dir.	Time domain Nonlinear	Time domain Linear	Frequency domain Direct.	Frequency domain Unidirect.
203	8	Bow	0.85	0.45	0.43	0.43
204	8	Quarter	0.92	0.77	0.61	0.83
206	16	Quarter	1.34	1.50	1.52	1.84
209	13	Bow	1.12	0.46	0.47	0.42
210	15	Quarter	1.60	1.65	1.78	2.06
303	8	Bow	1.18	0.53	0.51	0.59
304	8	Quarter	1.36	0.97	0.82	1.00
305	8	Bow	1.80	0.76	0.63	0.68
306	8	Quarter	1.05	1.35	0.95	1.13
309	14	Bow	0.84	0.43	0.42	0.41
310	14	Quarter	1.61	1.37	1.42	1.95
403	8	Bow	1.29	0.51	0.49	0.60
404	8	Quarter	1.04	1.18	0.87	1.12
409	16	Bow	0.76	0.45	0.45	0.41
410	16	Quarter	1.51	1.55	1.83	2.01
413	8	Beam	1.22	0.71	0.56	0.27

Table 26: Measured and Predicted Yaw Zero-Crossing Period for HMCS NIPIGON

Run	Speed	Relative	Time domain		Frequency domain	
	(knots)	sea dir.	Nonlinear	Linear	Direct.	Unidirect.
203	8	Bow	17.4	9.9	8.6	7.4
204	8	Quarter	15.5	14.5	10.5	11.2
206	16	Quarter	13.4	14.1	14.0	13.3
209	13	Bow	15.9	7.8	7.3	6.5
210	15	Quarter	15.5	15.8	15.4	15.6
303	8	Bow	23.7	11.0	9.6	8.6
304	8	Quarter	18.1	14.1	11.9	12.9
305	8	Bow	19.7	9.9	7.8	7.7
306	8	Quarter	12.1	13.9	10.4	12.2
309	14	Bow	14.6	8.3	7.9	7.1
310	14	Quarter	16.2	15.8	15.5	14.1
403	8	Bow	22.8	9.1	8.4	8.5
404	8	Quarter	13.8	15.6	11.4	11.2
409	16	Bow	14.9	10.2	9.2	6.6
410	16	Quarter	18.1	19.5	19.5	15.8
413	8	Beam	18.1	10.9	8.3	7.7

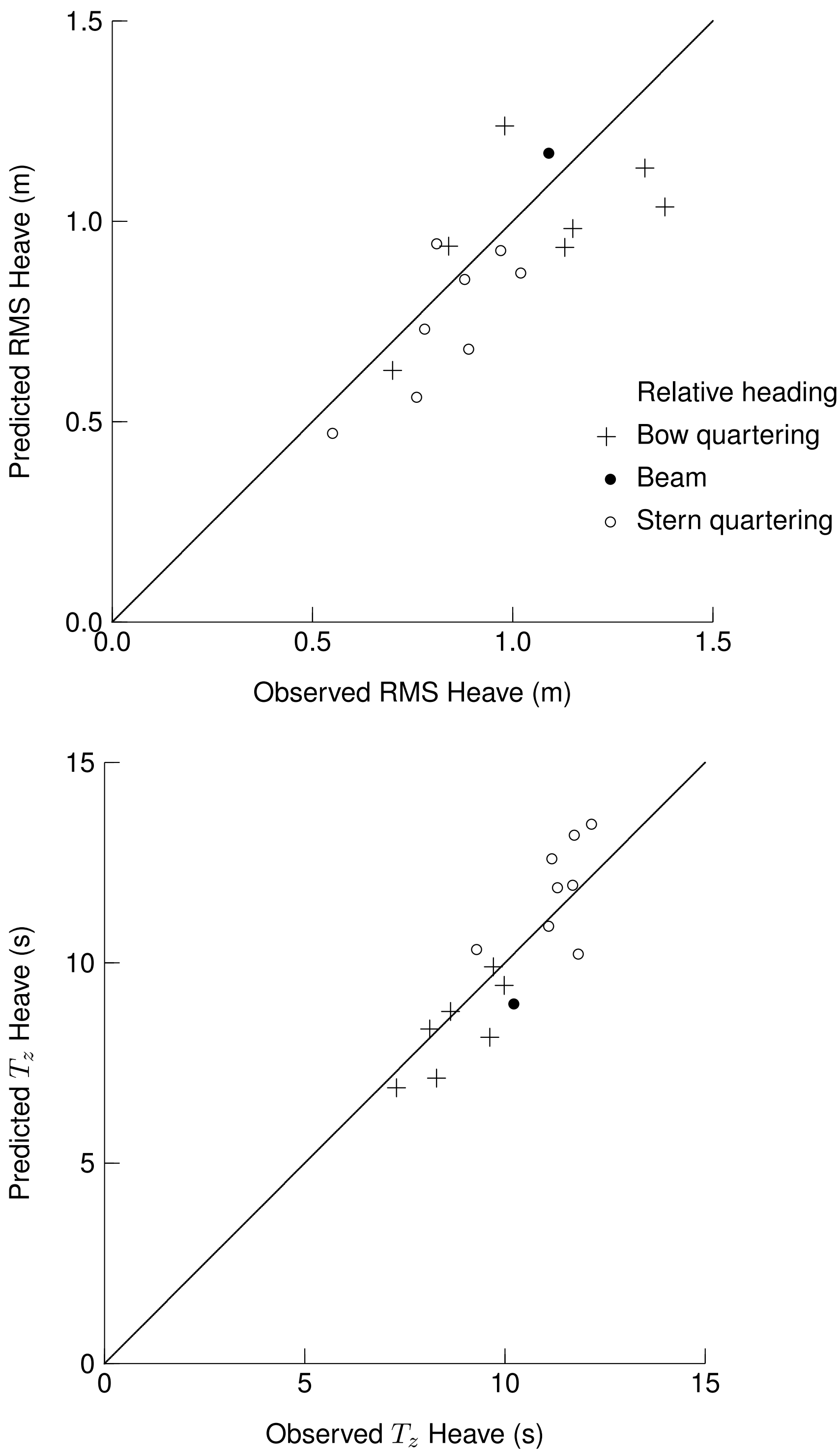

Figure 23: *Predicted Versus Observed RMS and Zero-Crossing Period for Heave, HMCS NIPIGON Trials and ShipMo3D Time Domain Predictions with Linear Incident Wave and Buoyancy Forces*

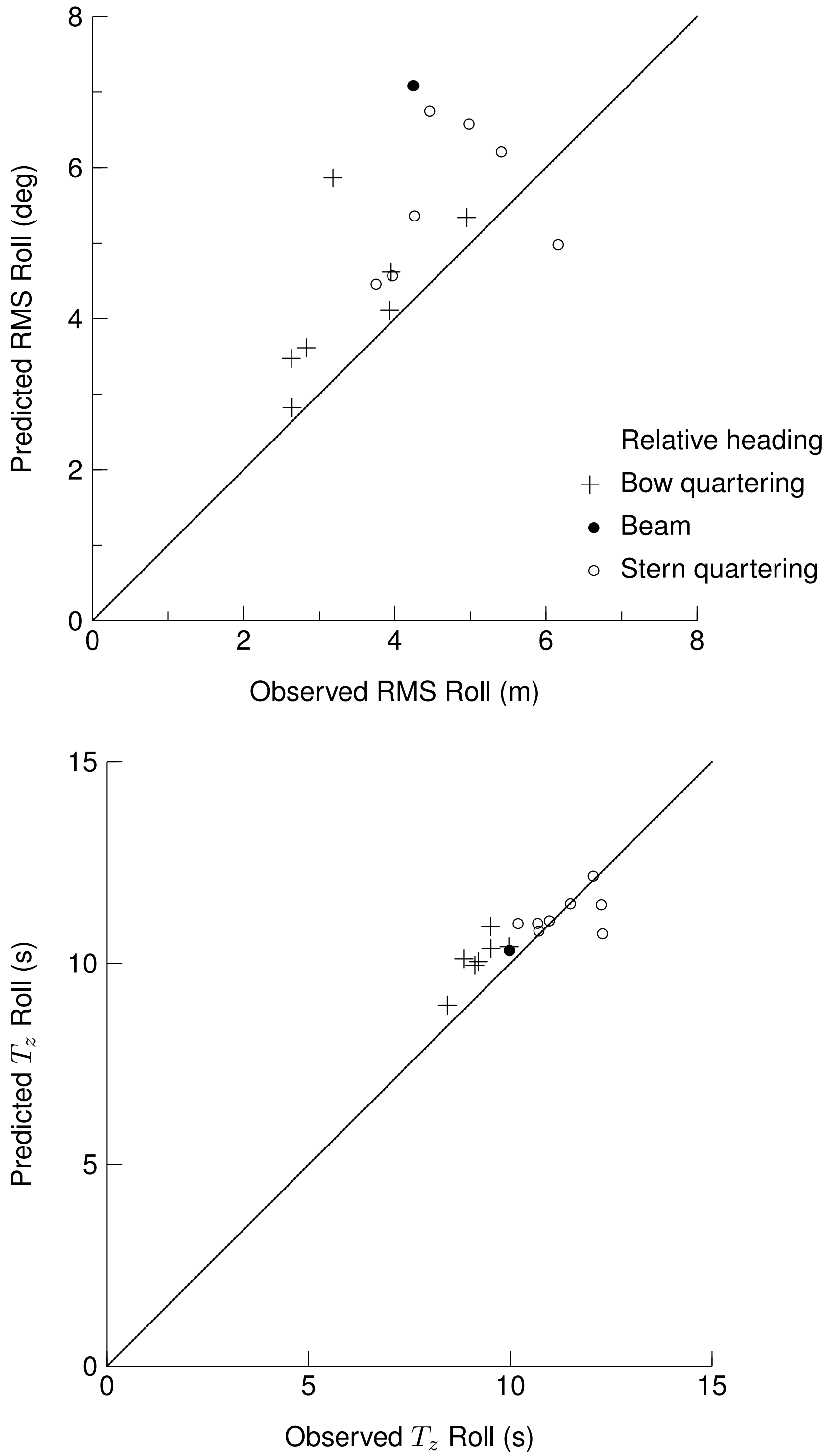

Figure 24: *Predicted Versus Observed RMS and Zero-Crossing Period for Roll, HMCS NIPIGON Trials and ShipMo3D Time Domain Predictions with Linear Incident Wave and Buoyancy Forces*

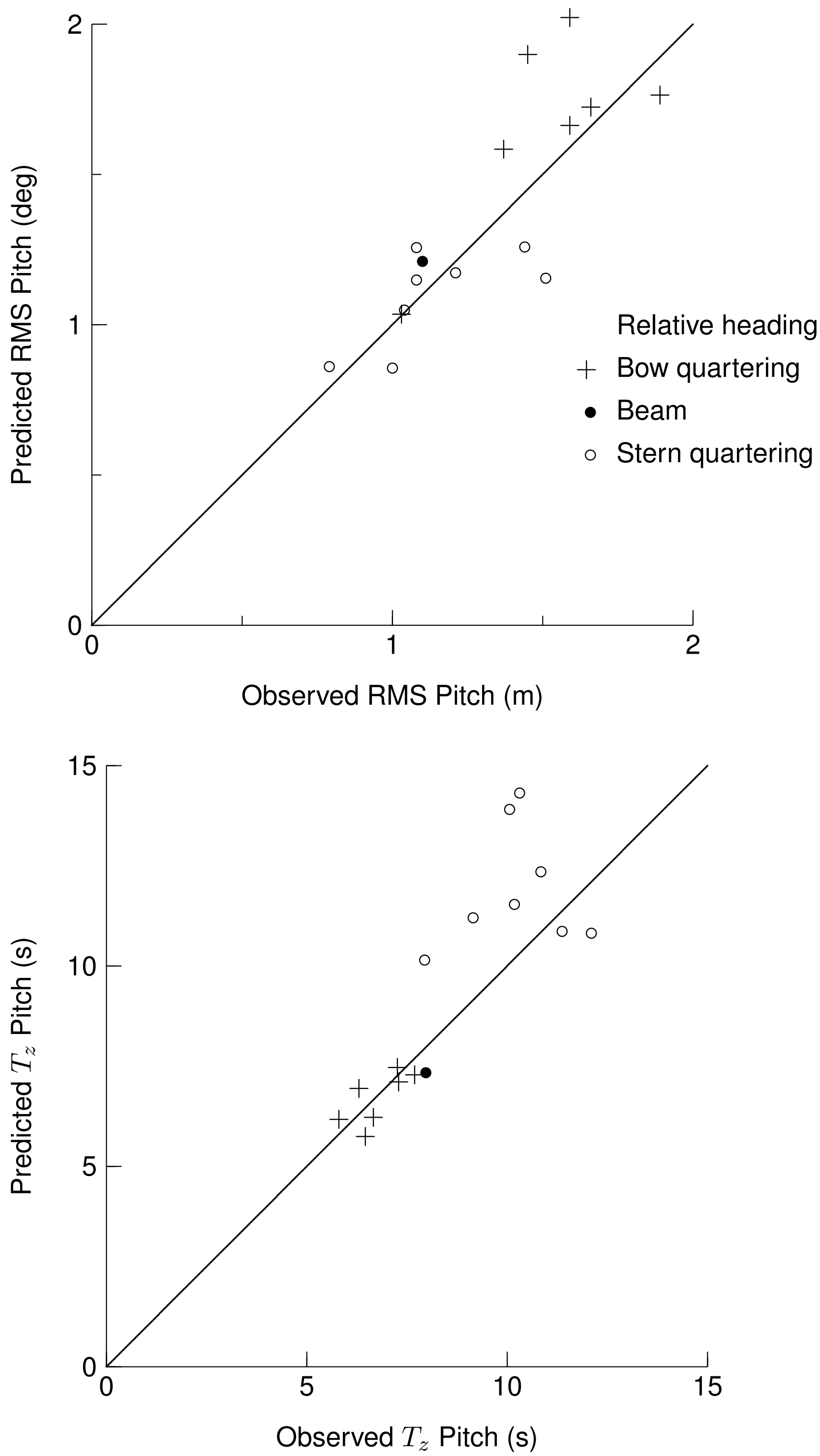

Figure 25: *Predicted Versus Observed RMS and Zero-Crossing Period for Pitch, HMCS NIPIGON Trials and ShipMo3D Time Domain Predictions with Linear Incident Wave and Buoyancy Forces*

4 Turning Circle Maneuvers for the Tanker Esso Osaka from Full-Scale Maneuvering Trials

A well documented set of maneuvering trials for the tanker Esso Osaka is the best known source of full-scale validation data for maneuvering predictions [16]. The Esso Osaka has subsequently been used in many maneuvering validation studies, as discussed by a specialist committee of the 2002 International Towing Tank Conference [17]. Table 27 gives particulars for the Esso Osaka. The ship included a single rudder with a span of 13.85 m and chord length of 9.0 m, and a single propeller with a diameter of 9.1 m.

Table 27: *Main Particulars for the Esso Osaka During Maneuvering Trials*

Length, L (between perpendiculars)	325 m
Beam, B	53 m
Midships draft, T_{mid}	21.73 m
Trim by stern, t_{stern}	0.0 m
Displacement, $\triangle$	319,400 tonnes
Longitudinal CG forward of midship	10.3 m

4.1 ShipMo3D Input Files for Esso Osaka Maneuvering Trials

Annex C gives ShipMo3D input files for the Esso Osaka. Annex C.1 gives the SM3DPanelHull input file for panelling the hull. This file uses the file *eoPatch.inp*, which has required hull geometric data. SM3DPanelHull models the hull as the following surfaces represented by bidirectional B-splines:

- flat bottom from station 0 to 19.5 (the aft perpendicular is located at station 20),
- main hull from fore perpendicular to the transom (station 0.0 to 20.0),
- lower hull forward of fore perpendicular, including bulbous bow,
- upper hull forward of fore perpendicular,
- transom,

- deck.

Annex C.3 gives the SM3DRadDif input file for radiation and diffraction computations. SM3DRadDif was run more than once such that appropriate limits on condition numbers could be selected for suppression of irregular frequencies.

Annex C.4 gives the SM3DBuildShip input file for creating a time domain model of the ship. Figure 26 shows graphical output of the ship model from SM3DBuildShip. For the hull, only the wetted portion is shown in Figure 26. The rudder is shown in red and the propeller is shown in blue.

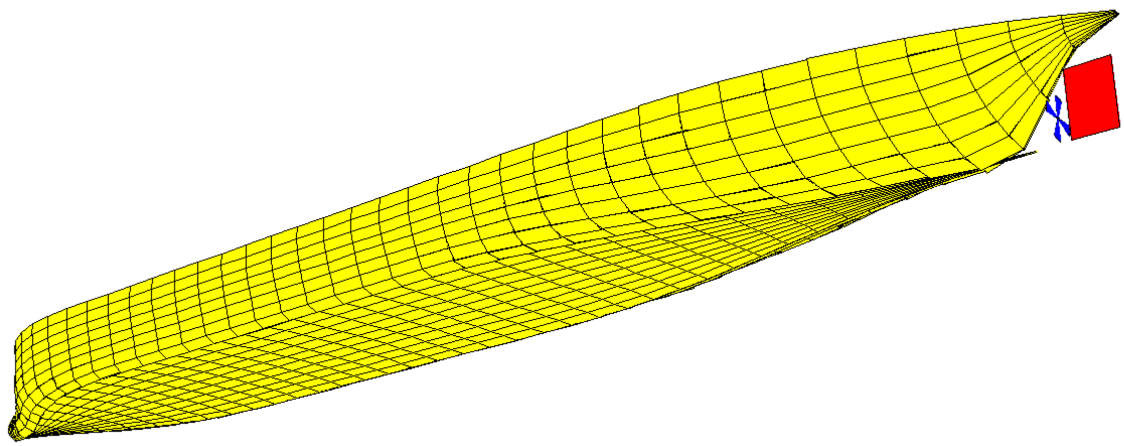

Figure 26: *ShipMo3D Model for Esso Osaka*

Due to lack of available data, some of the input parameters for the Esso Osaka had to be estimated. Resistance coefficients were taken from the Series 60 hull with C_B = 0.80 [18], which has geometric properties very similar to the Esso Osaka. Based on data given in Reference 12, the wake fraction w_{prop} was estimated to be 0.352 and the thrust deduction coefficient t_{prop} was estimated to be 0.2. The variation of propeller thrust coefficient with advance ratio was based on a representative curve from Reference 12 with a minor correction factor such that a speed of 10 knots was obtained for propeller speed of 51 RPM, as reported by Crane [16]. The rudder-propeller interaction coefficient was estimated to be 0.66 based on the ratio of the propeller diameter to the rudder span. The rudder flow straightening coefficient was estimated to be 0.4 based on data given in Reference 17. Hull maneuvering coefficients were determined using experimental values presented in Reference 17, with Reference 6 giving details on conversion of the experimental values to ShipMo3D values.

Annex C.5 gives the SM3DFreeMo input file for simulating a turning circle with an initial ship speed of 10 knots. The input file for a turning circle with an initial speed

of 7.7 knots was very similar, with changes to the propeller RPM, initial ship speed, and rudder deflection sign.

4.2 Comparisons of Numerical Predictions and Experimental Results for Esso Osaka Turning Circles

Table 28 and Figures 27 to 32 show results for turning circles at 10 knots and 7.7 knots. The results from sea trials given in Table 28 are nominal values based on the available sea trial data. Agreement between ShipMo3D predictions and trials results is generally good. For observed data, there is more scatter for the data at the lower initial speed of 7.7 knots. This increased scatter is likely due to the ship being more susceptible to environmental forces at the lower ship speed. The predicted turning circle parameters in Table 28 are within 18 percent of measured values. Note that a time of 1500 s was selected for comparing ship speed and yaw rate in the latter part of the turn because the sea trial data appears to have greater scatter at later times.

It should be noted that the good agreement between the current predictions and trials data is due partly to the availability of experimentally determined hull maneuvering coefficients. Predictions in Reference 6 give poorer agreement when using hull maneuvering coefficients estimated using the approach of Inoue et al. [19]. However, the current predictions serve the purpose of validating ShipMo3D predictions using the best available input data.

Table 28: *Turning Circle Parameters for Esso Osaka*

	Sea trials	ShipMo3D
Initial ship speed of 10 knots		
Tactical diameter	1011 m	1030 m
Speed V at 1500 s	3.3 knots	2.7 knots
Absolute yaw rate $\lvert\dot{\chi}\rvert$ at 1500 s	0.29 deg/s	0.24 deg/s
Initial ship speed of 7.7 knots		
Tactical diameter	1006 m	1037 m
Speed V at 1500 s	2.2 knots	2.2 knots
Absolute yaw rate $\lvert\dot{\chi}\rvert$ at 1500 s	0.18 deg/s	0.19 deg/s

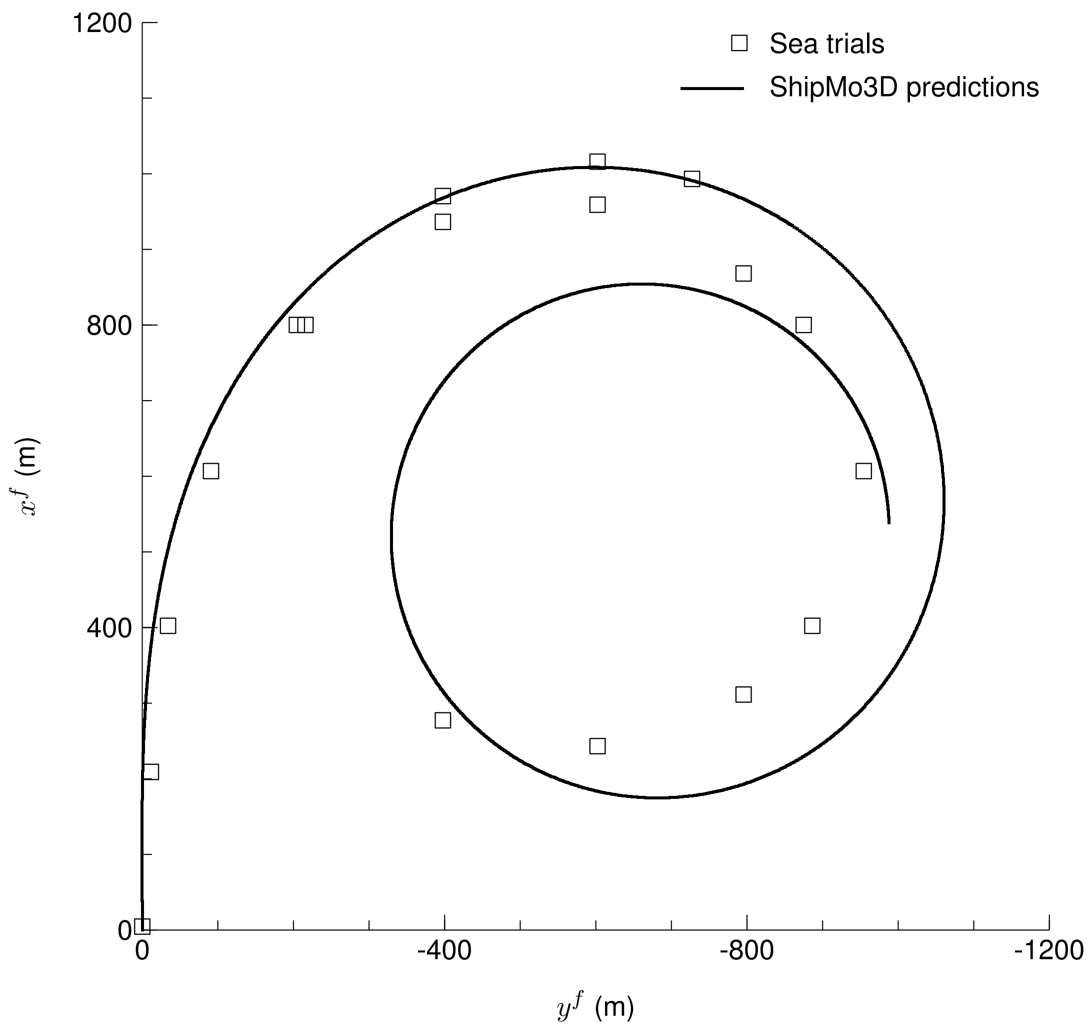

Figure 27: *Esso Osaka Trajectory During Turning Circle, Initial Speed of 10 knots*

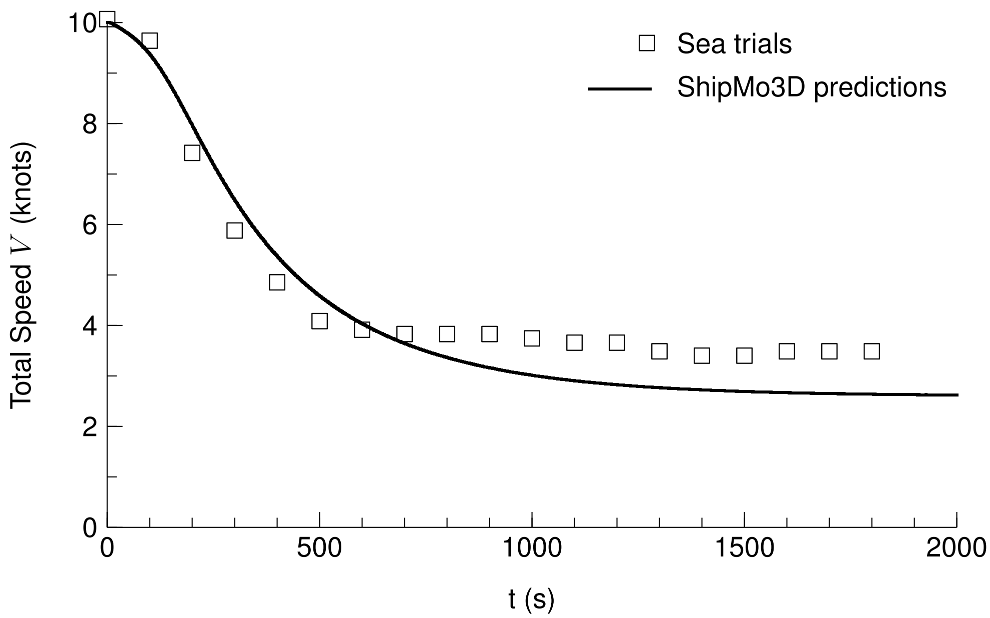

Figure 28: *Esso Osaka Total Speed During Turning Circle, Initial Speed of 10 knots*

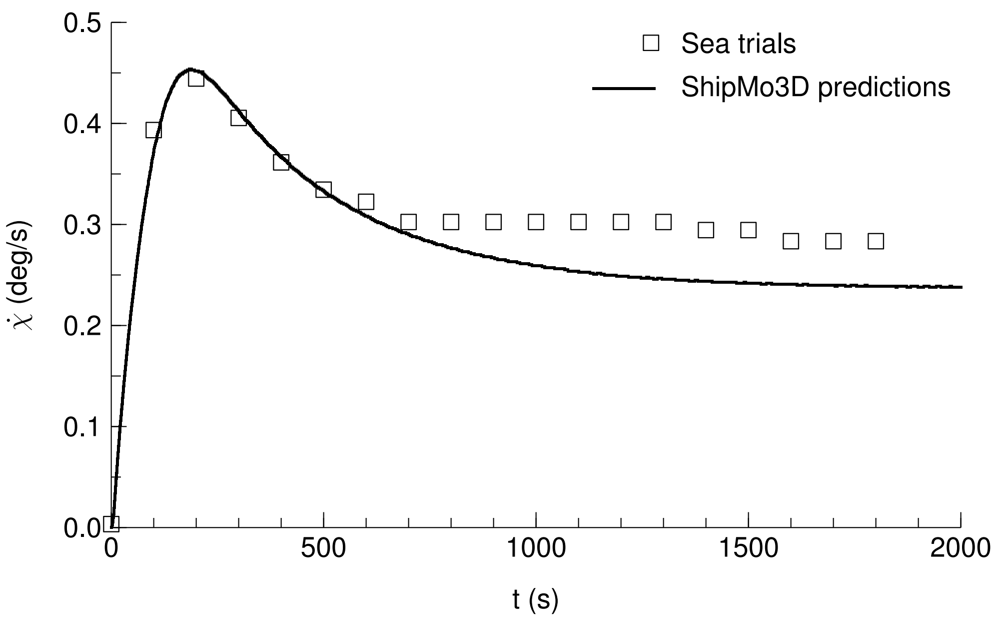

Figure 29: *Esso Osaka Yaw Rate During Turning Circle, Initial Speed of 10 knots*

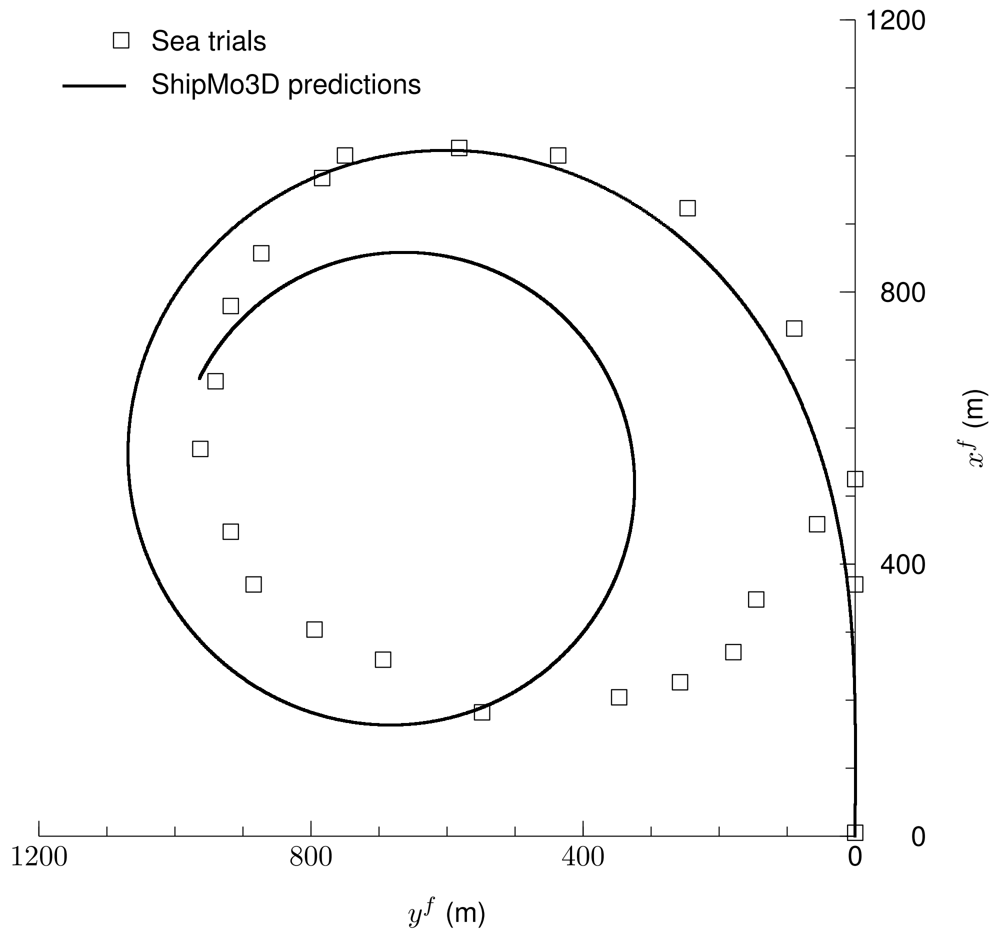

Figure 30: *Esso Osaka Trajectory During Turning Circle, Initial Speed of 7.7 knots*

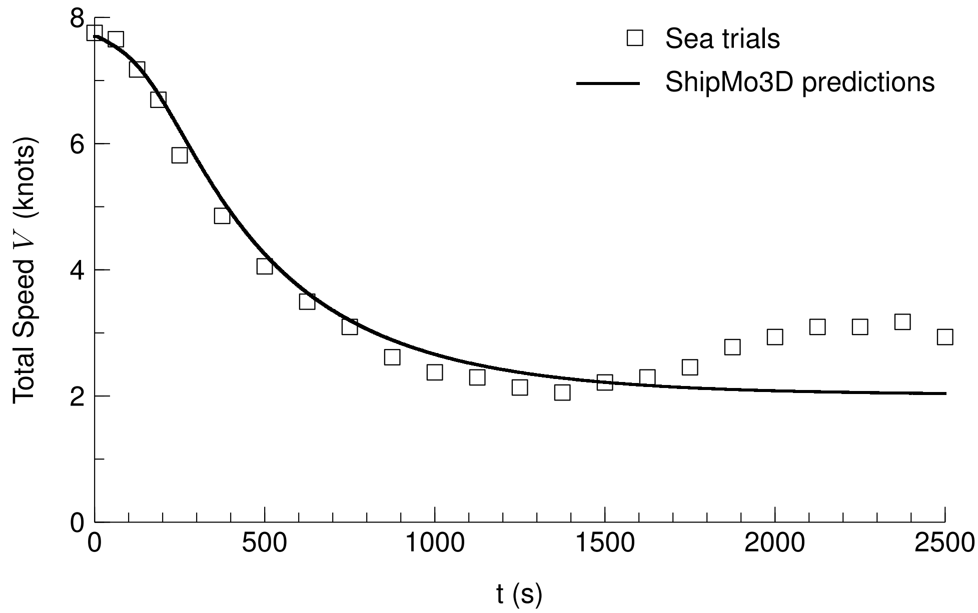

Figure 31: *Esso Osaka Total Speed During Turning Circle, Initial Speed of 7.7 knots*

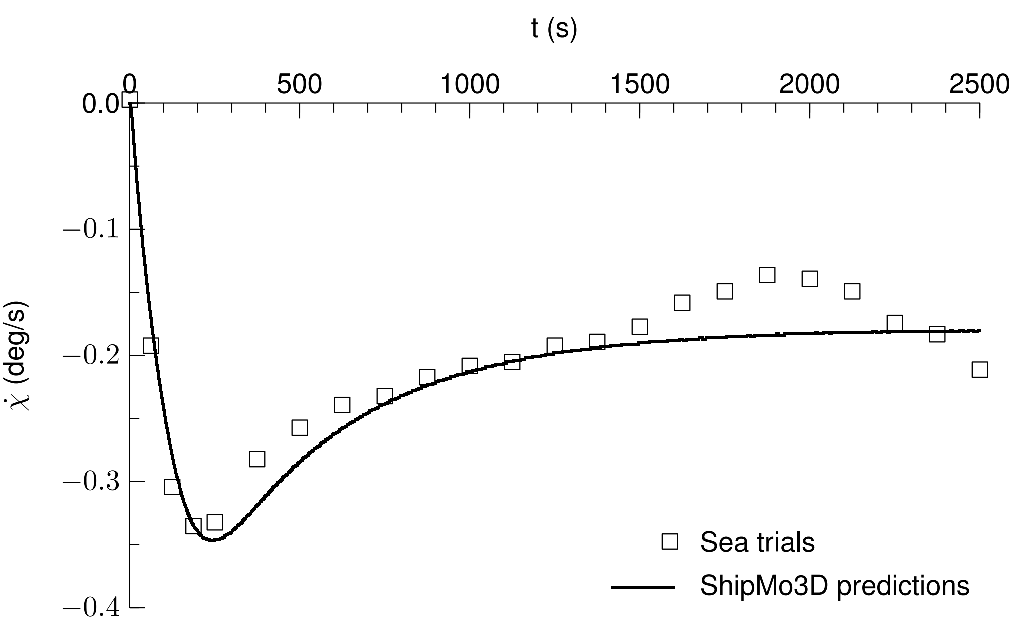

Figure 32: *Esso Osaka Yaw Rate During Turning Circle, Initial Speed of 7.7 knots*

5 Conclusions

Seakeeping and maneuvering predictions for the ShipMo3D library have been validated using data from model experiments and full-scale trials. For a ship travelling with steady speed in a random seaway of moderate steepness, predicted RMS motions are typically within 10 to 30 percent of observed values depending on the mode, with heave predictions being the most accurate and roll predictions being the least accurate. Predicted zero-crossing periods are typically within 10 percent of observed values. The highest differences between predicted observed motions were for RMS roll of HMCS NIPIGON during sea trials, and these differences could be partly due to uncertainties regarding rudder autopilot settings and measured wave conditions.

Turning circle predictions for the Esso Osaka give good agreement with measurements from full-scale trials, with predicted parameters (tactical diameter, and speed and yaw rate at 1500 s) being within 18 percent of measured values. It should be noted that ShipMo3D input for the Esso Osaka included hull maneuvering coefficients from experiments [17]. In the absence of experimental hull maneuvering coefficients, turning circle predictions would likely be less accurate.

References

[1] McTaggart, K.A. (2002). Three Dimensional Ship Hydrodynamic Coefficients Using the Zero Forward Speed Green Function. (DRDC Atlantic TM 2002-059). Defence Research and Development Canada - Atlantic.

[2] McTaggart, K.A. (2003). Hydrodynamic Forces and Motions in the Time Domain for an Unappended Ship Hull. (DRDC Atlantic TM 2003-104). Defence Research and Development Canada - Atlantic.

[3] McTaggart, K.A. (2003). Modelling and Simulation of Seaways in Deep Water for Simulation of Ship Motions. (DRDC Atlantic TM 2003-190). Defence Research and Development Canada - Atlantic.

[4] McTaggart, K.A. (2004). Appendage and Viscous Forces for Ship Motions in Waves. (DRDC Atlantic TM 2004-227). Defence Research and Development Canada - Atlantic.

[5] McTaggart, K.A. (2005). Simulation of Hydrodynamic Forces and Motions for a Freely Maneuvering Ship in a Seaway. (DRDC Atlantic TM 2005-071). Defence Research and Development Canada - Atlantic.

[6] McTaggart, K.A. (2007). Improved Maneuvering Forces and Autopilot Modelling for the ShipMo3D Ship Motion Library. (DRDC Atlantic TM 2007-174). Defence Research and Development Canada - Atlantic.

[7] McTaggart, K.A. (2007). ShipMo3D Version 1.0 User Manual for Simulating Motions of a Freely Maneuvering Ship in a Seaway. (DRDC Atlantic TM 2007-172). Defence Research and Development Canada - Atlantic.

[8] McTaggart, K.A. (2007). ShipMo3D Version 1.0 User Manual for Frequency Domain Analysis of Ship Seakeeping in a Seaway. (DRDC Atlantic TM 2007-171). Defence Research and Development Canada - Atlantic.

[9] Lloyd, A.R.J.M. and Crossland, P. (1990). Motions of a Steered Model Warship in Oblique Waves. *Transactions, Royal Institution of Naval Architects*, **132**, 79–98.

[10] McTaggart, K. and Stredulinsky, D. (2004). Validation of Ship Motion Predictions with Sea Trials Data for a Naval Destroyer in Multidirectional Seas. In *25th Symposium on Naval Hydrodynamics*, St. John's, Canada.

[11] Holtrop, J. and Mennen, G.G.J. (1982). An Approximate Power Prediction Method. *International Shipbuilding Progress*, **29**(335), 166–170.

[12] van Manen, J.D. and van Oossanen, P. (1988). Principles of Naval Architecture, Volume II, Ch. 6, Propulsion. Society of Naval Architects and Marine Engineers.

[13] Lewandowski, E. M. (2004). The Dynamics of Marine Craft - Maneuvering and Seakeeping, Vol. 22 of *Advanced Series on Ocean Engineering*. River Edge, New Jersey: World Scientific.

[14] Stredulinsky, D.C., Pegg, N.G., and Gilroy, L.E. (2000). Motion and Wave Load Predictions and Measurements on HMCS NIPIGON. *Transactions, Royal Institution of Naval Architects*, Vol. 142.

[15] McTaggart, K.A. and Stredulinsky, D. (2001). Comparisons of Motions for HMCS NIPIGON with Numerical Predictions. (DREA ECR 2001-156). Defence Research Establishment Atlantic.

[16] Crane, C.L., Jr. (1979). Maneuvering Trials of the 278,000 DWT Esso Osaka in Shallow and Deep Water. *Transactions, Society of Naval Architects and Marine Engineers*, Vol. 87.

[17] (2002). The Specialist Committee on Esso Osaka - Final Recommendations to the 23rd ITTC. In *23rd International Towing Tank Conference*, Vol. II, pp. 573–609. The Hague.

[18] Todd, F.H. (1953). Some Further Experiments on Single-Screw Merchant Ship Forms - Series 60. *Transactions, Society of Naval Architects and Marine Engineers*, **61**, 516–589.

[19] Inoue, S., Hirano, M., and Kijima, K. (1981). Hydrodynamic Derivatives on Ship Manoeuvring. *International Shipbuilding Progress*, **28**(321), 112–125.

This page intentionally left blank.

Symbols and Abbreviations

AP	aft perpendicular
a	wave amplitude
B	ship beam
C_B	ship block coefficient
g	gravitational acceleration
$\overline{GM}$	metacentric height
$\overline{GM}_{fluid}$	metacentric height, including fluid effects
H_s	significant wave height
$\overline{KG}$	vertical centre of gravity relative to baseline
k	wavenumber
$k^D_{\delta j}$	autopilot derivative gain for mode j
$k^I_{\delta j}$	autopilot integral gain for mode j
$k^P_{\delta j}$	autopilot proportional gain for mode j
L	ship length between perpendiculars
RMS	root-mean-square
r_{xx}, r_{yy}, r_{zz}	radii of gyration in roll, pitch, and yaw
T_{mid}	draft at midships
T_p	peak wave period
T_z	zero-crossing period
t	time
t_{stern}	trim by stern
V	total ship speed in horizontal plane
x_f, y_f	horizontal plane coordinates in earth-fixed axes
γ^r	rudder flow straightening constant
δ^{rudder}	rudder deflection angle
δ^{rudder}_{max}	maximum rudder deflection angle
$\dot{\delta}^{rudder}$	rudder deflection velocity
$\dot{\delta}^{rudder}_{max}$	maximum rudder deflection velocity
$\ddot{\delta}^{rudder}$	rudder deflection acceleration
δ^{rudder}_C	command rudder angle
ζ_δ	rudder control damping coefficient
η_j	motion displacement in translating earth axes for mode j
η^f_j	motion displacement in earth-fixed axes for mode j
η^f_{Cj}	command motion displacement in earth-fixed axes for mode j

$\dot{\eta}_j^f$	motion velocity in earth-fixed axes for mode j
τ	time integration variable
τ_{max}^{rudder}	autopilot integration duration
$\dot{\chi}$	yaw velocity
ω_I	incident wave frequency
ω_δ	rudder control natural frequency
$\triangle$	ship mass displacement

Annex A: ShipMo3D Input Files for Haslar Steered Warship Model

A.1 SM3DPanelHull Input File swPanelHull.inp for Haslar Steered Warship Model

```
begin SM3DPanelHull
label Steered warship from Lloyd and Crossland, RINA Trans 1990.
runOption full
patchHullFileName swPatch.inp
plotOutOption screen
begin patchPlots
    patchPlotOptions png includeStarboard
    patchPlotFileName patchFrontLowerView.png
    patchViewPoint 5.0 5.0 -3.0
    patchZoomFactor 1.2
    patchImageSize 150.0 100.0
end patchPlots
wetPanelFileName swWetPanelHull.pkl
dryPanelOption dryPanel
dryPanelFileName swDryPanelHull.pkl
waterDensity 1000.0
draftTrim 0.196 0.0
shipKG 0.276
splineInterpOption twoDimen
panelParameters 0.005 3.0 15.0
begin panelPlots
    panelPlotType wet
        panelPlotOptions png rain includeStarboard nonSmooth
        panelPlotFileName wetFrontLowerView.png
        panelViewPoint 5.0 5.0 -3.0
        panelZoomFactor 1.5
        panelImageSize 150.0 100.0
    panelPlotType wet
        panelPlotOptions png rain includeStarboard nonSmooth
        panelPlotFileName wetBackView.png
        panelViewPoint -10.0 0.0 0.0
        panelZoomFactor 1.5
        panelImageSize 150.0 100.0
     panelPlotType wet
        panelPlotOptions png rain includeStarboard nonSmooth
```

```
        panelPlotFileName wetFrontView.png
        panelViewPoint 10.0 0.0 0.0
        panelZoomFactor 1.5
        panelImageSize 150.0 100.0
    panelPlotType wet
        panelPlotOptions png rain includeStarboard nonSmooth
        panelPlotFileName wetSideView.png
        panelViewPoint 0.0 20.0 0.0
        panelZoomFactor 1.0
        panelImageSize 150.0 100.0
    panelPlotType wet
        panelPlotOptions png rain includeStarboard nonSmooth
        panelPlotFileName wetBottomView.png
        panelViewPoint 0.0 0.0 -20.0
        panelZoomFactor 1.0
        panelImageSize 150.0 100.0
end panelPlots
end SM3DPanelHull
```

A.2 Patch Hull Input File swPatch.inp for Haslar Steered Warship Model

```
begin patchHull
label Steered Warship from Lloyd and Crossland, 1990 RINA Trans.
lengthData 5.58 20.0 0.0
#############################################
begin patch
label keel Stations -1 to 0
normalRanges 0.5 1.0 0.0 0.1 -1.0 -0.5
begin hullLine
    station -1
    yOffsets 0.0
    zOffsets 0.54
end hullLine
begin hullLine
    station 0
    yOffsets   0.000   0.002
    zOffsets   0.181   0.181
end hullLine
end patch
##################################################
begin patch
label keel Stations 0 to 20
normalRanges -0.5 1.0 -0.1 0.1 -1.0 -0.5
begin hullLine
    station 0
    yOffsets   0.000   0.002
    zOffsets   0.181   0.181
end hullLine
begin hullLine
    station 1
    yOffsets   0.000   0.002
    zOffsets   0.018   0.018
end hullLine
begin hullLine
    station 2
    yOffsets   0.000   0.006
    zOffsets   0.013   0.013
end hullLine
begin hullLine
    station 3
```

```
    yOffsets   0.000   0.007
    zOffsets   0.010   0.010
end hullLine
begin hullLine
    station 4
    yOffsets   0.000   0.008
    zOffsets   0.009   0.009
end hullLine
begin hullLine
    station 5
    yOffsets   0.000   0.009
    zOffsets   0.007   0.007
end hullLine
begin hullLine
    station 6
    yOffsets   0.000   0.009
    zOffsets   0.006   0.006
end hullLine
begin hullLine
    station 7
    yOffsets   0.000   0.009
    zOffsets   0.005   0.005
end hullLine
begin hullLine
    station 8
    yOffsets   0.000   0.009
    zOffsets   0.003   0.003
end hullLine
begin hullLine
    station 9
    yOffsets   0.000   0.009
    zOffsets   0.002   0.002
end hullLine
begin hullLine
    station 10
    yOffsets   0.000   0.009
    zOffsets   0.000   0.000
end hullLine
begin hullLine
    station 11
    yOffsets   0.000   0.009
    zOffsets  -0.002  -0.002
```

```
end hullLine
begin hullLine
    station 12
    yOffsets   0.000   0.009
    zOffsets  -0.003  -0.003
end hullLine
begin hullLine
    station 13
    yOffsets   0.000   0.014
    zOffsets  -0.005  -0.005
end hullLine
begin hullLine
    station 14
    yOffsets   0.000   0.015
    zOffsets  -0.006  -0.006
end hullLine
begin hullLine
    station 15
    yOffsets   0.000   0.017
    zOffsets  -0.007  -0.007
end hullLine
begin hullLine
    station 16
    yOffsets   0.000   0.018
    zOffsets  -0.008  -0.008
end hullLine
begin hullLine
    station 17
    yOffsets   0.000   0.009
    zOffsets   0.076   0.076
end hullLine
begin hullLine
    station 18
    yOffsets   0.000   0.007
    zOffsets   0.134   0.134
end hullLine
begin hullLine
    station 19
    yOffsets   0.000   0.005
    zOffsets   0.164   0.164
end hullLine
begin hullLine
```

```
    station 20
    yOffsets   0.000   0.003
    zOffsets   0.176   0.176
end hullLine
end patch
##############################################################
begin patch
label hull Stations -1 to 0
normalRanges -0.5 0.5 0.0 1.0 -1.0 0.1
begin hullLine
    station -1
    yOffsets 0.0
    zOffsets 0.54
end hullLine
begin hullLine
    station 0
    yOffsets   0.002   0.005   0.009   0.020   0.035   0.052   0.068 !
               0.084   0.100   0.120   0.150
    zOffsets   0.181   0.209   0.250   0.289   0.336   0.380   0.418 !
               0.452   0.473   0.500   0.532
end hullLine
end patch
##########################################################
begin patch
label hull Stations 0 to 20
normalRanges -0.5 0.5 -0.1 1.0 -1.0 0.1
begin hullLine
    station 0
    yOffsets   0.002   0.005   0.009   0.020   0.035   0.052   0.068 !
               0.084   0.100   0.120   0.150
    zOffsets   0.181   0.209   0.250   0.289   0.336   0.380   0.418 !
               0.452   0.473   0.500   0.532
end hullLine
begin hullLine
    station 1
    yOffsets   0.002   0.008   0.014   0.019   0.028   0.036   0.047 !
               0.069   0.103   0.148   0.213
    zOffsets   0.018   0.041   0.065   0.091   0.125   0.155   0.191 !
               0.253   0.339   0.430   0.522
end hullLine
begin hullLine
    station 2
```

```
    yOffsets   0.006   0.018   0.032   0.045   0.061   0.082   0.095 !
               0.132   0.161   0.206   0.259
    zOffsets   0.013   0.039   0.064   0.091   0.123   0.159   0.191 !
               0.266   0.326   0.418   0.506
end hullLine
begin hullLine
    station 3
    yOffsets   0.007   0.032   0.052   0.075   0.101   0.122   0.143 !
               0.177   0.207   0.239   0.298
    zOffsets   0.010   0.038   0.061   0.089   0.125   0.157   0.190 !
               0.252   0.318   0.384   0.486
end hullLine
begin hullLine
    station 4
    yOffsets   0.008   0.045   0.074   0.105   0.136   0.164   0.190 !
               0.218   0.250   0.276   0.320
    zOffsets   0.009   0.034   0.056   0.085   0.117   0.152   0.191 !
               0.241   0.306   0.370   0.463
end hullLine
begin hullLine
    station 5
    yOffsets   0.009   0.059   0.095   0.133   0.175   0.206   0.233 !
               0.257   0.280   0.299   0.328
    zOffsets   0.007   0.025   0.047   0.075   0.114   0.151   0.191 !
               0.235   0.286   0.348   0.444
end hullLine
begin hullLine
    station 6
    yOffsets   0.009   0.066   0.111   0.150   0.195   0.241   0.270 !
               0.288   0.302   0.318   0.339
    zOffsets   0.006   0.017   0.036   0.061   0.097   0.145   0.191 !
               0.227   0.275   0.341   0.430
end hullLine
begin hullLine
    station 7
    yOffsets   0.009   0.070   0.118   0.191   0.239   0.268   0.295 !
               0.309   0.322   0.334   0.347
    zOffsets   0.005   0.011   0.025   0.064   0.107   0.143   0.191 !
               0.227   0.273   0.336   0.418
end hullLine
begin hullLine
    station 8
```

```
    yOffsets   0.009   0.077   0.145   0.195   0.243   0.282   0.314 !
               0.325   0.334   0.345   0.355
    zOffsets   0.003   0.007   0.023   0.045   0.082   0.128   0.191 !
               0.227   0.273   0.334   0.409
end hullLine
begin hullLine
    station 9
    yOffsets   0.009   0.077   0.147   0.202   0.248   0.295   0.325 !
               0.339   0.350   0.357   0.361
    zOffsets   0.002   0.003   0.017   0.034   0.064   0.118   0.191 !
               0.238   0.294   0.356   0.407
end hullLine
begin hullLine
    station 10
    yOffsets   0.009   0.077   0.147   0.205   0.249   0.300   0.334 !
               0.343   0.355   0.364   0.366
    zOffsets   0.000   0.001   0.014   0.030   0.052   0.114   0.191 !
               0.232   0.290   0.352   0.405
end hullLine
begin hullLine
    station 11
    yOffsets   0.009   0.091   0.136   0.182   0.233   0.285   0.317 !
               0.339   0.348   0.356   0.364   0.368
    zOffsets  -0.002   0.001   0.011   0.023   0.045   0.091   0.136 !
               0.191   0.227   0.273   0.318   0.405
end hullLine
begin hullLine
    station 12
    yOffsets   0.009   0.091   0.136   0.166   0.218   0.276   0.314 !
               0.339   0.348   0.356   0.364   0.368
    zOffsets  -0.003   0.001   0.014   0.023   0.045   0.091   0.136 !
               0.191   0.227   0.273   0.318   0.405
end hullLine
begin hullLine
    station 13
    yOffsets   0.014   0.091   0.139   0.189   0.261   0.305   0.332 !
               0.343   0.352   0.359   0.368
    zOffsets  -0.005   0.007   0.023   0.045   0.091   0.136   0.191 !
               0.227   0.273   0.318   0.405
end hullLine
begin hullLine
    station 14
```

```
    yOffsets   0.015   0.063   0.125   0.200   0.238   0.288   0.322 !
               0.335   0.345   0.352   0.364
    zOffsets  -0.006   0.011   0.034   0.068   0.091   0.136   0.191 !
               0.227   0.273   0.318   0.405
end hullLine
begin hullLine
    station 15
    yOffsets   0.017   0.049   0.091   0.182   0.241   0.288   0.309 !
               0.325   0.336   0.345   0.356
    zOffsets  -0.007   0.023   0.043   0.080   0.114   0.157   0.191 !
               0.227   0.273   0.318   0.405
end hullLine
begin hullLine
    station 16
    yOffsets   0.018   0.020   0.039   0.091   0.182   0.241   0.293 !
               0.311   0.327   0.335   0.348
    zOffsets  -0.008   0.023   0.045   0.073   0.106   0.136   0.191 !
               0.227   0.273   0.318   0.407
end hullLine
begin hullLine
    station 17
    yOffsets   0.009   0.045   0.091   0.132   0.170   0.230   0.270 !
               0.293   0.311   0.325   0.336
    zOffsets   0.076   0.091   0.105   0.117   0.130   0.157   0.191 !
               0.227   0.273   0.318   0.409
end hullLine
begin hullLine
    station 18
    yOffsets   0.007   0.027   0.091   0.141   0.183   0.216   0.231 !
               0.264   0.290   0.307   0.320
    zOffsets   0.134   0.136   0.143   0.152   0.164   0.182   0.191 !
               0.227   0.273   0.318   0.411
end hullLine
begin hullLine
    station 19
    yOffsets   0.005   0.026   0.057   0.091   0.124   0.152   0.182 !
               0.232   0.264   0.282   0.305
    zOffsets   0.164   0.165   0.167   0.170   0.175   0.182   0.191 !
               0.227   0.273   0.318   0.414
end hullLine
begin hullLine
    station 20
```

```
    yOffsets   0.003   0.020   0.039   0.061   0.082   0.098   0.120 !
               0.195   0.236   0.257   0.286
    zOffsets   0.176   0.177   0.180   0.182   0.184   0.186   0.191 !
               0.227   0.273   0.318   0.416
end hullLine
end patch
################################################################
begin patch
label transom
normalRanges -1.0 -0.9 -0.01 0.01 -0.01 0.01
begin hullLine
    station 20
    yOffsets   0.286
    zOffsets   0.416
end hullLine
begin hullLine
    station 20
    yOffsets   0.257   0.257
    zOffsets   0.318   0.416
end hullLine
begin hullLine
    station 20
    yOffsets   0.236   0.236
    zOffsets   0.273   0.416
end hullLine
begin hullLine
    station 20
    yOffsets   0.195   0.195
    zOffsets   0.227   0.416
end hullLine
begin hullLine
    station 20
    yOffsets   0.120   0.120
    zOffsets   0.191   0.416
end hullLine
begin hullLine
    station 20
    yOffsets   0.098   0.098
    zOffsets   0.186   0.416
end hullLine
begin hullLine
    station 20
```

```
    yOffsets   0.082   0.082
    zOffsets   0.184   0.416
end hullLine
begin hullLine
    station 20
    yOffsets   0.061   0.061
    zOffsets   0.182   0.416
end hullLine
begin hullLine
    station 20
    yOffsets   0.039   0.039
    zOffsets   0.180   0.416
end hullLine
begin hullLine
    station 20
    yOffsets   0.020   0.020
    zOffsets   0.177   0.416
end hullLine
begin hullLine
    station 20
    yOffsets   0.003   0.003
    zOffsets   0.176   0.416
end hullLine
begin hullLine
    station 20
    yOffsets   0.000   0.000
    zOffsets   0.176   0.416
end hullLine
end patch
################################################################
begin patch
label deck Stations -1 to 0
normalRanges -0.1 0.1 -0.1 0.1 0.9 1.0
begin hullLine
    station -1
    yOffsets 0.0
    zOffsets 0.54
end hullLine
begin hullLine
    station 0
    yOffsets   0.150   0.000
    zOffsets   0.532   0.532
```

```
end hullLine
end patch
################################################################
begin patch
label deck Stations 0 to 20
normalRanges -0.1 0.1 -0.1 0.1 0.9 1.0
begin hullLine
    station 0
    yOffsets   0.150   0.000
    zOffsets   0.532   0.532
end hullLine
begin hullLine
    station 1
    yOffsets   0.213   0.000
    zOffsets   0.522   0.522
end hullLine
begin hullLine
    station 2
    yOffsets   0.259   0.000
    zOffsets   0.506   0.506
end hullLine
begin hullLine
    station 3
    yOffsets   0.298   0.000
    zOffsets   0.486   0.486
end hullLine
begin hullLine
    station 4
    yOffsets   0.320   0.000
    zOffsets   0.463   0.463
end hullLine
begin hullLine
    station 5
    yOffsets   0.328   0.000
    zOffsets   0.444   0.444
end hullLine
begin hullLine
    station 6
    yOffsets   0.339   0.000
    zOffsets   0.430   0.430
end hullLine
begin hullLine
```

```
    station 7
    yOffsets   0.347   0.000
    zOffsets   0.418   0.418
end hullLine
begin hullLine
    station 8
    yOffsets   0.355   0.000
    zOffsets   0.409   0.409
end hullLine
begin hullLine
    station 9
    yOffsets   0.361   0.000
    zOffsets   0.407   0.407
end hullLine
begin hullLine
    station 10
    yOffsets   0.366   0.000
    zOffsets   0.405   0.405
end hullLine
begin hullLine
    station 11
    yOffsets   0.368   0.000
    zOffsets   0.405   0.405
end hullLine
begin hullLine
    station 12
    yOffsets   0.368   0.000
    zOffsets   0.405   0.405
end hullLine
begin hullLine
    station 13
    yOffsets   0.368   0.000
    zOffsets   0.405   0.405
end hullLine
begin hullLine
    station 14
    yOffsets   0.364   0.000
    zOffsets   0.405   0.405
end hullLine
begin hullLine
    station 15
    yOffsets   0.356   0.000
```

```
    zOffsets   0.405   0.405
end hullLine
begin hullLine
    station 16
    yOffsets   0.348   0.000
    zOffsets   0.407   0.407
end hullLine
begin hullLine
    station 17
    yOffsets   0.336   0.000
    zOffsets   0.409   0.409
end hullLine
begin hullLine
    station 18
    yOffsets   0.320   0.000
    zOffsets   0.411   0.411
end hullLine
begin hullLine
    station 19
    yOffsets   0.305   0.000
    zOffsets   0.414   0.414
end hullLine
begin hullLine
    station 20
    yOffsets   0.286   0.000
    zOffsets   0.416   0.416
end hullLine
end patch
end patchHull
```

A.3 SM3DRadDif Input File swRadDif.inp for Haslar Steered Warship Model

```
begin SM3DRadDif
label Steered Warship from Lloyd and Crossland, 1990 RINA Trans.
wetPanelFileName swWetPanelHull.pkl
radDifDBFileName swRadDifDB.pkl
loadCondition 1000.0 0.196 0.0 0.276
hydroCompOptions 7.0 1.0e6 5.0 5.0 sourceGauss Galerkin 2
enFreqRange 0.5 30.0 0.5
begin condLimits
    enFreqsLongLimits 1.0 30.0
    condLimitsLong    2500 2500
    enFreqsLatLimits 1.0 30.0
    condLimitsLat    1200 1200
end condLimits
froudes 0.0 0.15 0.18 0.26 0.27 0.28 0.36 0.37 0.40 0.45
seaDirDegRange 0.0 180.0 15.0
waveFreqRange 1.0 6.0 0.2
diffracOption diffrac
plotOption screenFile
end SM3DRadDif
```

A.4 SM3DBuildShip Input File swFreeBuildShip.inp for Building Time Domain Ship Model of Haslar Steered Warship Model

```
begin SM3DBuildShip
label Steered Warship from Lloyd and Crossland, 1990 RINA Trans.
shipType freeTD
radDifDBFileName swRadDifDB.pkl
shipDBFileName swFreeShip.pkl
dryPanelOption dryPanel
dryPanelFileName swDryPanelHull.pkl
loadCondition 1000.0 0.196 0.0 0.276
correctionGM 0.0
gyradii 0.257 1.293 1.265
tRetardIncMax 0.02 4.0
enFreqIntIncMax 0.5 30.0
begin hullViscous
    speedsResist 0.5 1.0 1.5 2.0 2.5 3.0 3.5
    resistOption HoltropMennen
    hullDragCo 1.17 0.0
end hullViscous
begin hullManeuver
    hullManMethod Inoue
end hullManeuver
begin appendages
    begin bilgeKeel
       pairOption pair
       label Bilge keel
       stations    6.79  7     8     9     9.69
       yRoots      0.239 0.239 0.243 0.248 0.248
       zBlRoots    0.107 0.107 0.082 0.064 0.064
       spans       0.068 0.068 0.068 0.068 0.068
       dihedralsDeg -45  -45  -45  -45  -45  -45  -45  -45 -45
    end bilgeKeel
    begin foil
        pairOption pair
        label Forward outer shaft bracket
        dimen 17.97 0.157 0.125 0.068 0.012 0.012 -90.0
    end foil
    begin foil
        pairOption pair
```

```
        label Forward inner shaft bracket
        dimen 17.97 0.072 0.103 0.081 0.012 0.012 -42.0
    end foil
    begin foil
        pairOption pair
        label Aft outer shaft bracket
        dimen 18.40 0.132 0.163 0.127 0.030 0.030 -99.5
    end foil
    begin foil
        pairOption pair
        label Aft inner shaft bracket
        dimen 18.40 0.021 0.148 0.165 0.030 0.030 -47.5
    end foil
    begin foil
        pairOption pair
        label Stabiliser (fixed)
        dimen 10.38 0.273 0.075 0.083 0.174 0.092 -46.0
    end foil
    begin rudder
        pairOption pair
        label Rudder
        dimen 19.46 0.079 0.178 0.153 0.124 0.088 -83.0
        incFlowCo 0.0 0.7
        autopilotParam 35.0 100.0 0.0 25.8 0.85 0.02
        dispGains 0.0 0.0 0.0 0.0 0.0 -3.8
        velGains 0.0 0.0 0.0 0.0 0.0 -1.7
    end rudder
end appendages
begin propellers
    begin fixedPitchPropeller
        pairOption pair
        label Propeller
        dimen 18.6 0.120 0.03 0.20
        propCo 0.0 0.0
        thrustCoQuadratic 0.4 -0.20 -0.15
        propControlParam 0.0 1200.0 -5.0 -1.0 20.0 0.8 50.0 0.0 0.02
    end fixedPitchPropeller
end propellers
begin rudderPropCo
    rudderPropCo 0 0.9 0.0
    rudderPropCo 1 0.0 0.9
end rudderPropCo
```

```
shipPlotOutOption screenFile
begin shipPlots
    shipPlotOptions png hullAppProp includeStarboard nonSmooth
    shipPlotFileName shipAftLowerView.png
    viewPoint -20.0 20.0 -10.0
    zoomFactor 2.5
    imageSizeShip 300.0 200.0
    cropStations -1.0e6 1.0e6
    shipPlotOptions png hullAppProp includeStarboard nonSmooth
    shipPlotFileName shipAftView.png
    viewPoint -20.0 0.0 0.0
    zoomFactor 1.0
    imageSizeShip 150.0 100.0
    cropStations -1.0e6 1.0e6
end shipPlots
retardPlotOption screenFile
rpmSpeedOption rpmSpeed
paramRpmSpeed 2 1200 0.02 50.0
indicesPropRpm 0 1
speedsRpm 1.331 1.923 1.997 2.071 2.662 2.736 # Exp Froudes
end SM3DBuildShip
```

A.5 SM3DSeakeepRegular Input File swSeakeepRegular for Haslar Steered Warship Model

```
begin SM3DSeakeepRegular
label Steered Warship from Lloyd and Crossland, 1990 RINA Trans.
steadyShipDBFDFileName swShipFD.pkl
loadCondition 1000.0 0.196 0.0 0.276 0.0
outOptions outRudderRao outRollDamp
outRaoPprOption noOutRaoPpr
enFreqMinMotion 0.4
froudes 0.18 0.26 0.27 0.28 0.36 0.37
seaDirsDeg 0.0 30.0 60.0 75.0 90.0 120.0 150.0 180.0
waveFreqRange 2.0 4.6 0.1
waveAmpOption constantSteepness
waveSteepness 0.02
end SM3DSeakeepRegular
```

A.6 SM3DBuildSeaway Input File buildSeaway20.inp for Haslar Steered Warship Model, Wave Frequency 2.0 rad/s

```
begin SM3DBuildSeaway
label Regular seaway, waveFreq 2.0 rad/s, steepness 1/50
seawayFileName regSeaway20.pkl
waterDensity 1000.0
sampleParams 10.0 0.02
seawayType regular
begin regularSeaway
    regularParam 360.000 2.000000 0.154032 0.000000
    regNonlinearOption Wheeler
end regularSeaway
end SM3DBuildSeaway
```

A.7 SM3DFreeMo Input File freeMoBase.inp for Haslar Steered Warship Model, Relative Sea Direction 0 degrees, Froude Number 0.18, Wave Frequency 2.0 rad/s

```
begin SM3DFreeMo
label Steered warship in calm water
freeShipDBTDFileName swFreeShip.pkl
loadCondition 1000.0 0.196 0.0 0.276 0.0
seawayOption waves
seawayFileName regSeaway20.pkl
timeParameters 0.02 0.0 10.0 10.0
nonLinearOption linear
dispsFixed0MDeg 0.0 0.0 0.0 0.0 0.0 0.0
speed0 0.0
rudderDeflects0Deg 0.0 0.0
rudderVels0Deg 0.0 0.0
rpmsPropellers0 938.5 938.5
begin maneuvers
    setRpm -1 938.5
    setCourse -1 0.0
    elapsedTime 100.0
end maneuvers
outTimeIntervals 0.02 10.0
outTimeSeries disp noVel noAcc
outRudderProp noRudder noProp
plotOption noPlots
end SM3DFreeMo
```

Annex B: ShipMo3D Input Files for HMCS NIPIGON Sea Trials

B.1 SM3DPanelHull Input File nipigonPanelHull.inp for HMCS NIPIGON

```
begin SM3DPanelHull
label NIPIGON for 1997 ship motion and sea load trial
runOption full
patchHullFileName nipigonPatch.inp
plotOutOption screen
begin patchPlots
    patchPlotOptions png includeStarboard
    patchPlotFileName patchFrontLowerView.png
    patchViewPoint 120.0 120.0 -60.0
    patchZoomFactor 1.4
    patchImageSize 150.0 100.0
end patchPlots
wetPanelFileName nipigonWetPanelHull.pkl
dryPanelOption dryPanel
dryPanelFileName nipigonDryPanelHull.pkl
waterDensity 1025.0
draftTrim 4.245 0.496
shipKG 5.081
splineInterpOption twoDimen
panelParameters 1.5 3.0 15.0
begin panelPlots
    panelPlotType wetDry
        panelPlotOptions png rain includeStarboard nonSmooth
        panelPlotFileName wetDryFrontLowerView.png
        panelViewPoint 120.0 120.0 -60.0
        panelZoomFactor 1.5
        panelImageSize 150.0 100.0
    panelPlotType wetDry
        panelPlotOptions png rain includeStarboard nonSmooth
        panelPlotFileName wetDryBackView.png
        panelViewPoint -200.0 0.0 0.0
        panelZoomFactor 1.5
        panelImageSize 150.0 100.0
     panelPlotType wetDry
        panelPlotOptions png rain includeStarboard nonSmooth
```

```
        panelPlotFileName wetDryFrontView.png
        panelViewPoint 200.0 0.0 0.0
        panelZoomFactor 1.5
        panelImageSize 150.0 100.0
    panelPlotType wetDry
        panelPlotOptions png rain includeStarboard nonSmooth
        panelPlotFileName wetDrySideView.png
        panelViewPoint 0.0 500.0 0.0
        panelZoomFactor 1.5
        panelImageSize 150.0 100.0
    panelPlotType wetDry
        panelPlotOptions png rain includeStarboard nonSmooth
        panelPlotFileName wetDryBottomView.png
        panelViewPoint 0.0 0.0 -500.0
        panelZoomFactor 1.3
        panelImageSize 150.0 100.0
end panelPlots
end SM3DPanelHull
```

B.2 Patch Hull Input File nipigonPatch.inp for HMCS NIPIGON

```
begin patchHull
label NIPIGON class
lengthData 108.5 20.0 54.25
##############################################################
begin patch
    label Hull stations -1.0 to 0.0
    normalRanges -0.2 0.8 -0.2 1.0 -1.0 0.2
    begin hullLine
        station -1.0
        yOffsets 0.0
        zOffsets 10.4
    end hullLine
    begin hullLine
        station 0.0
        yOffsets 0.0  2.0
        zOffsets 4.0  10.4
    end hullLine
end patch
##############################################################
begin patch
    label Hull stations 0.0 to 1.0 excluding keel.
    normalRanges -0.2 0.8 -0.2 1.0 -1.0 0.2
    begin hullLine
        station 0.0
        yOffsets 0.0  2.0
        zOffsets 4.0  10.4
    end hullLine
    begin hullLine
        station 1.0
        yOffsets 0.140 0.363 0.555 0.710 0.783 0.866 1.067 1.372
                 1.996 2.819  3.898
        zOffsets 0.000 0.844 2.012 3.027 3.417 3.844 4.734 5.742
                 7.266 8.772 10.366
    end hullLine
end patch
##############################################################
begin patch
    label Keel stations 0.0 to 1.0
    normalRanges -0.2 0.8 -0.2 1.0 -1.0 0.2
```

```
    begin hullLine
        station 0.0
        yOffsets 0.0
        zOffsets 4.0
    end hullLine
    begin hullLine
        station 1.0
        yOffsets 0.000 0.140
        zOffsets 0.000 0.000
    end hullLine
end patch
##############################################################
begin patch
    label Keel stations 1.0 to 20.0
    normalRanges -0.5 0.5  -0.001 0.001 -1.0 -0.9
    begin hullLine
        station 1.0
        yOffsets 0.000 0.140
        zOffsets 0.000 0.000
    end hullLine
    begin hullLine
        station 2.0
        yOffsets 0.000 0.149
        zOffsets 0.000 0.000
    end hullLine
    begin hullLine
        station 3.0
        yOffsets 0.000 0.149
        zOffsets 0.000 0.000
    end hullLine
    begin hullLine
        station 4.0
        yOffsets 0.000 0.149
        zOffsets 0.000 0.000
    end hullLine
    begin hullLine
        station 5.0
        yOffsets 0.000 0.168
        zOffsets 0.000 0.000
    end hullLine
    begin hullLine
        station 6.0
```

```
        yOffsets 0.000 0.158
        zOffsets 0.000 0.000
    end hullLine
    begin hullLine
        station 7.0
        yOffsets 0.000 0.158
        zOffsets 0.000 0.000
    end hullLine
    begin hullLine
        station 8.0
        yOffsets 0.000 0.149
        zOffsets 0.000 0.000
    end hullLine
    begin hullLine
        station 9.0
        yOffsets 0.000 0.149
        zOffsets 0.000 0.000
    end hullLine
    begin hullLine
        station 10.0
        yOffsets 0.000 0.140
        zOffsets 0.000 0.000
    end hullLine
    begin hullLine
        station 11.0
        yOffsets 0.000 0.131
        zOffsets 0.000 0.000
    end hullLine
    begin hullLine
        station 12.0
        yOffsets 0.000 0.131
        zOffsets 0.000 0.000
    end hullLine
    begin hullLine
        station 13.0
        yOffsets 0.000 0.131
        zOffsets 0.000 0.000
    end hullLine
    begin hullLine
        station 14.0
        yOffsets 0.000 0.122
        zOffsets 0.067 0.067
```

```
    end hullLine
    begin hullLine
        station 15.0
        yOffsets 0.000 0.122
        zOffsets 0.293 0.293
    end hullLine
    begin hullLine
        station 16.0
        yOffsets 0.000 0.155
        zOffsets 0.823 0.823
    end hullLine
    begin hullLine
        station 17.0
        yOffsets 0.000 0.140
        zOffsets 1.649 1.649
    end hullLine
    begin hullLine
        station 18.0
        yOffsets 0.000 0.116
        zOffsets 2.585 2.585
    end hullLine
    begin hullLine
        station 19.0
        yOffsets 0.000 0.116
        zOffsets 3.249 3.249
    end hullLine
    begin hullLine
        station 20.0
        yOffsets 0.000 0.116
        zOffsets 3.249 3.249
    end hullLine
end patch
###############################################################
begin patch
    label Hull stations 1.0 to 20.0 excluding transom and deck
    normalRanges -0.2 0.8 -0.2 1.0 -1.0 0.2
    begin hullLine
        station 1.0
        yOffsets 0.140 0.363 0.555 0.710 0.783 0.866 1.067 1.372 !
                 1.996 2.819  3.898
        zOffsets 0.000 0.844 2.012 3.027 3.417 3.844 4.734 5.742 !
                 7.266 8.772 10.366
```

```
    end hullLine
    begin hullLine
        station 2.0
        yOffsets 0.149 0.488 0.841 1.100 1.369 1.536 1.999 2.536 !
                 3.411 4.161 4.746
        zOffsets 0.000 0.439 1.103 1.817 2.652 3.219 4.587 5.913 !
                 7.748 9.086 9.952
    end hullLine
    begin hullLine
        station 3.0
        yOffsets 0.149 0.936 1.387 1.759 2.103 2.512 2.920 3.411 !
                 4.084 4.630 5.230
        zOffsets 0.000 0.613 1.125 1.847 2.588 3.584 4.563 5.752 !
                 7.218 8.321 9.571
    end hullLine
    begin hullLine
        station 4.0
        yOffsets 0.149 1.155 1.960 2.667 3.106 3.514 3.877 4.267 !
                 4.688 5.157 5.514
        zOffsets 0.000 0.469 1.177 2.173 3.039 3.892 4.749 5.749 !
                 6.803 8.193 9.248
    end hullLine
    begin hullLine
        station 5.0
        yOffsets 0.168 1.399 2.646 3.356 3.886 4.426 4.880 4.990 !
                 5.282 5.462 5.770
        zOffsets 0.000 0.396 1.274 2.091 2.975 4.106 5.285 5.736 !
                 6.742 7.623 8.931
    end hullLine
    begin hullLine
        station 6.0
        yOffsets 0.158 2.188 3.536 4.481 4.816 5.066 5.456 5.563 !
                 5.733 5.864 5.989
        zOffsets 0.000 0.588 1.506 2.676 3.228 3.825 5.078 5.685 !
                 6.605 7.684 8.577
    end hullLine
    begin hullLine
        station 7.0
        yOffsets 0.158 1.0   2.676 3.837 4.660 5.212 5.529 5.825 !
                 5.986 6.114 6.163 6.178
        zOffsets 0.000 0.214 0.640 1.222 1.948 2.755 3.420 4.426 !
                 5.669 7.263 8.135 8.391
```

```
end hullLine
begin hullLine
    station 8.0
    yOffsets 0.149 1.0   2.704 4.084 4.947 5.672 6.008 6.218 !
             6.239 6.294 6.297 6.322
    zOffsets 0.000 0.193 0.582 1.055 1.606 2.579 3.554 4.609 !
             5.636 6.901 7.763 8.278
end hullLine
begin hullLine
    station 9.0
    yOffsets 0.149 1.0   2.713 4.468 5.313 5.901 6.215 6.352 !
             6.398 6.383 6.376 6.383
    zOffsets 0.000 0.05  0.582 1.064 1.573 2.295 3.225 4.191 !
             5.803 6.760 7.596 8.242
end hullLine
begin hullLine
    station 10.0
    yOffsets 0.140 2.0   3.862 5.032 5.688 6.014 6.251 6.361 !
             6.401 6.392 6.376 6.383
    zOffsets 0.000 0.1   0.808 1.268 1.823 2.344 3.057 3.956 !
             4.913 6.315 7.333 8.077
end hullLine
begin hullLine
    station 11.0
    yOffsets 0.131 2.0   3.862 4.996 5.648 5.956 6.206 6.331 !
             6.392 6.383 6.376 6.383
    zOffsets 0.000 0.1   0.826 1.317 1.878 2.335 3.094 3.965 !
             4.913 6.315 7.333 8.077
end hullLine
begin hullLine
    station 12.0
    yOffsets 0.131 2.0  3.018 4.368 5.304 5.752 6.120 6.285 !
             6.373 6.373 6.376 6.373
    zOffsets 0.000 0.1  0.652 1.113 1.725 2.219 3.018 3.947 !
             4.913 6.315 7.333 8.077
end hullLine
begin hullLine
    station 13.0
    yOffsets 0.131 2.0   3.514 4.487 5.087 5.712 5.998 6.221 !
             6.343 6.355 6.358 6.355
    zOffsets 0.000 0.3   0.911 1.323 1.725 2.408 3.008 3.853 !
             4.913 6.315 7.343 8.077
```

```
end hullLine
begin hullLine
    station 14.0
    yOffsets 0.122 1.0   2.914 4.252 5.328 5.718 5.998 6.181 !
             6.279 6.328 6.331 6.325
    zOffsets 0.067 0.3   0.860 1.445 2.237 2.758 3.395 4.154 !
             4.913 6.315 7.324 8.077
end hullLine
begin hullLine
    station 15.0
    yOffsets 0.122 1.0   2.548 4.438 5.166 5.642 5.910 6.102 !
             6.175 6.242 6.236 6.233
    zOffsets 0.293 0.5   1.036 1.881 2.435 3.091 3.783 4.551 !
             4.923 6.315 7.333 8.077
end hullLine
begin hullLine
    station 16.0
    yOffsets 0.155 1.0   2.563 3.417 4.444 5.014 5.453 5.840 !
             5.913 5.998 6.020 6.035
    zOffsets 0.823 1.0   1.503 1.820 2.335 2.822 3.459 4.654 !
             4.901 6.312 7.330 8.077
end hullLine
begin hullLine
    station 17.0
    yOffsets 0.140 1.0   2.335 3.825 4.526 4.983 5.188 5.307 !
             5.517 5.669 5.721 5.742
    zOffsets 1.649 1.8   2.152 2.606 3.045 3.523 3.920 4.225 !
             4.901 6.291 7.321 8.077
end hullLine
begin hullLine
    station 18.0
    yOffsets 0.116 1.0    3.109 3.737 4.130 4.456 4.688 4.810 !
             4.974 5.182 5.297 5.377
    zOffsets 2.585 2.65   3.066 3.271 3.499 3.786 4.154 4.478 !
             4.907 6.297 7.318 8.077
end hullLine
begin hullLine
    station 19.0
    yOffsets 0.116 1.0   1.999 2.722 3.115 3.453 3.648 3.844 !
             4.039 4.212 4.535 4.752 4.907
    zOffsets 3.249 3.249 3.277 3.319 3.466 3.664 3.856 4.142 !
             4.520 4.901 6.294 7.315 8.077
```

```
    end hullLine
    begin hullLine
        station 20.0
        yOffsets 0.116 1.0   1.445 1.905 2.204 2.484 2.682 2.941 !
                 3.100 3.286 3.719 4.051 4.307
        zOffsets 3.249 3.280 3.295 3.344 3.450 3.612 3.795 4.154 !
                 4.496 4.895 6.288 7.321 8.077
    end hullLine
end patch
################################################################
begin patch
    label Transom
    normalRanges -1.0 -0.9 -0.001 0.001 -0.001 0.001
    areaPanelLimit 0.4
    begin hullLine
        station 20.0
        yOffsets 4.307
        zOffsets 8.077
    end hullLine
    begin hullLine
        station 20.0
        yOffsets 4.051 4.051
        zOffsets 7.321 8.077
    end hullLine
    begin hullLine
        station 20.0
        yOffsets 3.719 3.719
        zOffsets 6.288 8.077
    end hullLine
    begin hullLine
        station 20.0
        yOffsets 3.286 3.286
        zOffsets 4.895 8.077
    end hullLine
    begin hullLine
        station 20.0
        yOffsets 3.100 3.100
        zOffsets 4.496 8.077
    end hullLine
    begin hullLine
        station 20.0
        yOffsets 2.941 2.941
```

```
        zOffsets 4.154 8.077
    end hullLine
    begin hullLine
        station 20.0
        yOffsets 2.682 2.682
        zOffsets 3.795 8.077
    end hullLine
    begin hullLine
        station 20.0
        yOffsets 2.484 2.484
        zOffsets 3.612 8.077
    end hullLine
    begin hullLine
        station 20.0
        yOffsets 2.204 2.204
        zOffsets 3.450 8.077
    end hullLine
    begin hullLine
        station 20.0
        yOffsets 1.905 1.905
        zOffsets 3.344 8.077
    end hullLine
    begin hullLine
        station 20.0
        yOffsets 1.445 1.445
        zOffsets 3.295 8.077
    end hullLine
    begin hullLine
        station 20.0
        yOffsets 0.000 0.000
        zOffsets 3.249 8.077
    end hullLine
end patch
###################################################################
begin patch
    label Deck stations -1.0 to 10.0
    normalRanges -0.1 0.1 -0.1 0.1 0.9 1.0
    begin hullLine
        station  -1.0
        yOffsets 0.0
        zOffsets 10.4
    end hullLine
```

```
begin hullLine
    station  0
    yOffsets 2.0  0.0
    zOffsets 10.4 10.4
end hullLine
begin hullLine
    station  1
    yOffsets 3.898  0.0
    zOffsets 10.366 10.366
end hullLine
begin hullLine
    station  2
    yOffsets 4.746  0.0
    zOffsets 9.952 9.952
end hullLine
begin hullLine
    station  3
    yOffsets 5.230  0.0
    zOffsets 9.571 9.571
end hullLine
begin hullLine
    station  4
    yOffsets 5.514  0.0
    zOffsets 9.248 9.248
end hullLine
begin hullLine
    station  5
    yOffsets 5.770  0.0
    zOffsets 8.931 8.931
end hullLine
begin hullLine
    station  6
    yOffsets 5.989  0.0
    zOffsets 8.577 8.577
end hullLine
begin hullLine
    station  7
    yOffsets 6.178  0.0
    zOffsets 8.391 8.391
end hullLine
begin hullLine
    station  8
```

```
        yOffsets 6.322  0.0
        zOffsets 8.278 8.278
    end hullLine
    begin hullLine
        station  9
        yOffsets 6.383  0.0
        zOffsets 8.242 8.242
    end hullLine
    begin hullLine
        station  10
        yOffsets 6.383  0.0
        zOffsets 8.077 8.077
    end hullLine
end patch
##################################################################
begin patch
    label Deck, station 10 to station 20
    normalRanges -0.1 0.1 -0.1 0.1 0.9 1.0
    begin hullLine
        station  10
        yOffsets 6.383  0.0
        zOffsets 8.077 8.077
    end hullLine
    begin hullLine
        station  11
        yOffsets 6.383  0.0
        zOffsets 8.077 8.077
    end hullLine
    begin hullLine
        station  12
        yOffsets 6.373  0.0
        zOffsets 8.077 8.077
    end hullLine
    begin hullLine
        station  13
        yOffsets 6.355  0.0
        zOffsets 8.077 8.077
    end hullLine
    begin hullLine
        station  14
        yOffsets 6.325  0.0
        zOffsets 8.077 8.077
```

```
    end hullLine
    begin hullLine
        station  15
        yOffsets 6.233  0.0
        zOffsets 8.077 8.077
    end hullLine
    begin hullLine
        station  16
        yOffsets 6.035  0.0
        zOffsets 8.077 8.077
    end hullLine
    begin hullLine
        station  17
        yOffsets 5.742  0.0
        zOffsets 8.077 8.077
    end hullLine
    begin hullLine
        station  18
        yOffsets 5.377  0.0
        zOffsets 8.077 8.077
    end hullLine
    begin hullLine
        station  19
        yOffsets 4.907  0.0
        zOffsets 8.077 8.077
    end hullLine
    begin hullLine
        station  20
        yOffsets 4.307  0.0
        zOffsets 8.077 8.077
    end hullLine
end patch
end patchHull
```

B.3 SM3DRadDif Input File nipigonRadDif.inp for HMCS NIPIGON

```
begin SM3DRadDif
label NIPIGON for 1997 ship motion and sea load trial
wetPanelFileName nipigonWetPanelHull.pkl
radDifDBFileName nipigonRadDifDB.pkl
loadCondition 1025.0 4.245 0.496 5.081
hydroCompOptions 1.5 1.0e6 5.0 5.0 sourceGauss Galerkin 2
enFreqRange 0.1 6.0 0.1
begin condLimits
    enFreqsLongLimits 1.0 6.0
    condLimitsLong    1700 1700
    enFreqsLatLimits 1.0 6.0
    condLimitsLat     600 600
end condLimits
speedKnotsRange 0.0 30.0 5.0
seaDirDegRange 0.0 180.0 15.0
waveFreqRange 0.1 2.5 0.1
diffracOption diffrac
plotOption screenFile
end SM3DRadDif
```

B.4 SM3DBuildShip Input File nipigonTDBuildShip.inp for Building Time Domain Ship Model of HMCS NIPIGON

```
begin SM3DBuildShip
label NIPIGON for 1997 ship motion and sea load trial
shipType freeTD
radDifDBFileName nipigonRadDifDB.pkl
shipDBFileName nipigonFreeShip.pkl
dryPanelOption dryPanel
dryPanelFileName nipigonDryPanelHull.pkl
loadCondition 1025.0 4.245 0.496 5.081
correctionGM 0.0
gyradii 5.583 27.13 27.13
tRetardIncMax 0.1 15.0
enFreqIntIncMax 0.1 6.0
begin hullViscous
    speedsResistKnots 5.0 10.0 15.0 20.0 25.0 30.0 35.0
    resistOption HoltropMennen
    hullDragCo 1.17 0.0
end hullViscous
begin hullManeuver
    hullManMethod Inoue
end hullManeuver
begin appendages
    begin bilgeKeel
       pairOption pair
       label Bilge keel
       stations     8.82   10     11     12     13     13.79
       yRoots       5.775  5.734  5.623  5.559  5.553  5.578
       zBlRoots     2.207  1.867  1.848  1.959  2.203  2.448
       spans        0.61   0.61   0.61   0.61   0.61   0.61
       dihedralsDeg -45    -45    -45    -45    -45    -45
       bilgeKeelDamp SimplifiedKatoVelocity 1.0 1.0
    end bilgeKeel
    begin foil
        pairOption pair
        label Outer shaft bracket
        dimen 18.3 3.109 3.200 2.256 0.8 0.8 -99.5
    end foil
    begin foil
```

```
        pairOption pair
        label Inner shaft bracket
        dimen 18.3 1.158 2.957 2.240 0.8 0.8 -64.2
    end foil
    begin skeg
        pairOption single
        label Skeg
        stations     14.0   15.0   16.0   16.5
        yRoots       0.0    0.0    0.0    0.0
        zBlRoots     0.067  0.293  0.823  1.236
        spans        0.067  0.293  0.823  1.236
        dihedralsDeg -90.0  -90.0  -90.0  -90.0
    end skeg
    begin rudder
        pairOption pair
        label Rudder
        dimen 19.3 1.981 3.197 3.023 2.286 1.886 -90.0
        incFlowCo 0.0 0.7
        autopilotParam 35.0 3.0 0.0 0.2 0.85 0.1
        dispGains 0.0 0.0 0.0 0.0 0.0 -2.0
        velGains 0.0 0.0 0.0 0.0 0.0 -4.0
    end rudder
end appendages
# Approximation of actual propellers to keep this model UNCLASSIFIED
begin propellers
    begin fixedPitchPropeller
        pairOption pair
        label Propeller
        dimen 18.5 2.45 0.85 3.0
        propCo 0.0 0.0
        thrustCoQuadratic 0.4 -0.20 -0.16
        propControlParam 0.0 400 -5.0 -1.0 3.0 0.8 50.0 0.0 0.1
    end fixedPitchPropeller
end propellers
begin rudderPropCo
    rudderPropCo 0 0.9 0.0
    rudderPropCo 1 0.0 0.9
end rudderPropCo
shipPlotOutOption screenFile
begin shipPlots
    shipPlotOptions png hullAppProp includeStarboard nonSmooth
    shipPlotFileName shipAftLowerView.png
```

```
    viewPoint -120.0 120.0 -60.0
    zoomFactor 2.0
    imageSizeShip 300.0 200.0
    cropStations -1.0e6 1.0e6
    shipPlotOptions png hullAppProp includeStarboard nonSmooth
    shipPlotFileName shipAftView.png
    viewPoint -120.0 0.0 0.0
    zoomFactor 1.5
    imageSizeShip 150.0 100.0
    cropStations -1.0e6 1.0e6
end shipPlots
retardPlotOption screenFile
rpmSpeedOption rpmSpeed
paramRpmSpeed 2 400.0 0.2 300.0
indicesPropRpm 0 1
speedsKnotsRpm 5.0 8.0 10.0 13.0 14.0 15.0 16.0 20.0 25.0 30.0
end SM3DBuildShip
```

B.5 SM3DBuildSeaway Input File run203BuildSeaway.inp for HMCS NIPIGON Sea Trial Run 203

```
begin SM3DBuildSeaway
label Run 203 from 1997 NIPIGON trial
seawayFileName run203Seaway.pkl
waterDensity 1025.0
sampleParams 3600.0 0.1
seawayType dirSpectrum
begin dirSpectrumSeaway
    dirWaveFreqRange 0.2 2.0 0.05 randomInc 1001 1003
    dirWaveHeadingRange 0.0 360.0 10.0
    dirPhaseSeeds 1001 1009
    dirThreshold 1.0e-6
    dirSpectrumType EndecoWaveBuoy
    EndecoSpectrumFileName Spectra/R203.std
end dirSpectrumSeaway
plotOutOption screen
begin plots
    plotOptions png blueTurquoise smooth mesh
    plotFileName seawayPlot.png
    xfRange 0.0 400.0 10.0
    yfRange 0.0 400.0 10.0
    time 0.0
    viewPoint -100.0 -100.0 100.0
    zoomFactor 1.5
    imageSize 150.0 100.0
end plots
end SM3DBuildSeaway
```

B.6 SM3DFreeMo Input File run203NonlinearFreeMo.inp for HMCS NIPIGON Sea Trial Run 203

```
begin SM3DFreeMo
label NIPIGON 1997 trial run 203, nonlinear forces
freeShipDBTDFileName nipigonFreeShip.pkl
loadCondition 1025.0 4.245 0.496 5.081 0.0
seawayOption waves
seawayFileName run203Seaway.pkl
timeParameters 0.2 0.0 20.0 20.0
nonLinearOption nonLinear
dispsFixed0MDeg 0.0 0.0 0.0 0.0 0.0 265
speed0Knots 8.0
rudderDeflects0Deg 0.0 0.0
rudderVels0Deg 0.0 0.0
rpmsPropellers0 94.907 94.907
begin maneuvers
    setRpm -1 94.907
    setCourse -1 265
    elapsedTime 1820.0
end maneuvers
outTimeIntervals 10.0 100.0
outTimeSeries disp noVel noAcc
outRudderProp noRudder noProp
plotOption noPlots
end SM3DFreeMo
```

B.7 SM3DSeakeepSeaway Input File run203SeakeepSeaway.inp for HMCS NIPIGON Sea Trial Run 203

```
begin SM3DSeakeepSeaway
label NIPIGON run 203 of 1997 sea trial
steadyShipDBFDFileName nipigonFDShip.pkl
loadCondition 1025.0 4.245 0.496 5.081 0.0
enFreqMinMotion 0.1
speedsKnots 8.0
shipHeadingsDeg 265.0
spectrumType dirSpectrum
dirSpectrumType EndecoWaveBuoy
EndecoSpectrumFileName Spectra/R203.std
waveFreqRange 0.2 2.0 0.05
waveDirFromRange 0.0 360.0 10.0
end SM3DSeakeepRelative
```

B.8 SM3DSeakeepRandom Input File run203SeakeepRandom.inp for HMCS NIPIGON Sea Trials Run 203

```
begin SM3DSeakeepRandom
label NIPIGON 1997 sea trial run 203
steadyShipDBFDFileName nipigonFDShip.pkl
loadCondition 1025.0 4.245 0.496 5.081 0.0
outRaoOptions noOutMotionRao noOutRudderRao noOutRollDamp !
              noOutPositionRao noOutWaveKinRao
outRaoPprOption noOutRaoPpr
enFreqMinMotion 0.1
speedsKnots 8.0
seaDirsDeg 133.1
waveFreqRange 0.2 2.0 0.05
spectrumType inputSpectrum
inputWaveFreqs       0.440    0.503    0.565    0.628    0.691    !
                     0.754    0.817    0.880    0.942    1.005    !
                     1.068    1.131    1.194    1.257    1.319    !
                     1.382    1.445    1.508
inputEnergyDensities 0.000000 0.574868 3.206176 1.885031 1.772668 !
                     1.055834 0.673385 0.698054 1.101989 0.870896 !
                     0.515662 0.447385 0.250669 0.227273 0.236345 !
                     0.117456 0.202127 0.000000
spreadAngleDeg 0.0
end SM3DSeakeepRandom
```

Annex C: ShipMo3D Input Files for Esso Osaka Maneuvering Trials

C.1 SM3DPanelHull Input File EssoOsakaPanelHull.inp for Esso Osaka

```
begin SM3DPanelHull
label Esso Osaka from manuevering trials by Crane, 1979 SNAME Trans.
runOption full
patchHullFileName eoPatch.inp
plotOutOption screen
begin patchPlots
    patchPlotOptions png includeStarboard
    patchPlotFileName patchFrontLowerView.png
    patchViewPoint 300.0 300.0 -150.0
    patchZoomFactor 1.3
    patchImageSize 150.0 100.0
end patchPlots
wetPanelFileName EssoOsakaWetPanelHull.pkl
dryPanelOption dryPanel
dryPanelFileName EssoOsakaDryPanelHull.pkl
waterDensity 1025.0
draftTrim 21.73 0.0
shipKG 19.0
splineInterpOption twoDimen
panelParameters 30.0 3.0 15.0
begin panelPlots
    panelPlotType wetDry
        panelPlotOptions png rain includeStarboard nonSmooth
        panelPlotFileName wetDryFrontLowerView.png
        panelViewPoint 300.0 300.0 -150.0
        panelZoomFactor 1.5
        panelImageSize 150.0 100.0
    panelPlotType wetDry
        panelPlotOptions png rain includeStarboard nonSmooth
        panelPlotFileName wetDryBackView.png
        panelViewPoint -300.0 0.0 0.0
        panelZoomFactor 1.5
        panelImageSize 150.0 100.0
     panelPlotType wetDry
        panelPlotOptions png rain includeStarboard nonSmooth
```

```
        panelPlotFileName wetDryFrontView.png
        panelViewPoint 300.0 0.0 0.0
        panelZoomFactor 1.5
        panelImageSize 150.0 100.0
    panelPlotType wetDry
        panelPlotOptions png rain includeStarboard nonSmooth
        panelPlotFileName wetDrySideView.png
        panelViewPoint 0.0 1000.0 0.0
        panelZoomFactor 1.5
        panelImageSize 150.0 100.0
    panelPlotType wetDry
        panelPlotOptions png rain includeStarboard nonSmooth
        panelPlotFileName wetDryBottomView.png
        panelViewPoint 0.0 0.0 -1000.0
        panelZoomFactor 1.3
        panelImageSize 150.0 100.0
end panelPlots
end SM3DPanelHull
```

C.2 Patch Hull Input File eoPatch.inp for Esso Osaka

```
begin patchHull
label Esso Osaka
lengthData 325.0 20.0 162.5
begin patch
label Flat bottom stations 0 to 19.5
normalRanges 0.0 0.0  0.0 0.0 -1.0 -1.0
begin hullLine
station 0.000
        yOffsets  0.000  0.105
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 0.250
        yOffsets  0.000  0.773
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 0.500
        yOffsets  0.000  2.190
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 0.750
        yOffsets  0.000  4.410
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 1.000
        yOffsets  0.000  6.830
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 1.500
        yOffsets  0.000 11.500
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 2.000
        yOffsets  0.000 15.400
        zOffsets  0.000  0.000
```

```
end hullLine
begin hullLine
station 3.000
        yOffsets  0.000 21.000
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 4.000
        yOffsets  0.000 23.770
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 5.000
        yOffsets  0.000 24.400
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 6.000
        yOffsets  0.000 24.400
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 8.000
        yOffsets  0.000 24.400
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 10.000
        yOffsets  0.000 24.400
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 12.000
        yOffsets  0.000 23.918
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 13.000
        yOffsets  0.000 22.197
        zOffsets  0.000  0.000
end hullLine
begin hullLine
```

```
station 14.000
        yOffsets  0.000 19.219
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 15.000
        yOffsets  0.000 15.111
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 16.000
        yOffsets  0.000 10.520
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 17.000
        yOffsets  0.000  6.250
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 18.000
        yOffsets  0.000  2.828
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 18.500
        yOffsets  0.000  1.603
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 19.000
        yOffsets  0.000  0.798
        zOffsets  0.000  0.000
end hullLine
begin hullLine
station 19.500
        yOffsets  0.000  0.251
        zOffsets  0.000  0.000
end hullLine
end patch
#######################################################
begin patch
```

```
label Main hull from fore perpendicular to transom
normalRanges -0.5 0.5  0.0 1.0 -1.0 0.5
begin hullLine
station 0.000
        yOffsets  0.105  1.920  2.570  3.315  3.688  3.830  3.819 !
                  3.690  3.490  3.240  2.950  2.640  2.295  1.935 !
                  1.550  1.155  0.760  0.420  0.170  0.000  0.000 !
                  0.000  0.000  0.000  0.915  1.910  2.940  3.935 !
                  4.910  5.880  6.820  7.760
        zOffsets  0.000  0.500  1.000  2.000  3.000  4.000  5.000 !
                  6.000  7.000  8.000  9.000 10.000 11.000 12.000 !
                 13.000 14.000 15.000 16.000 17.000 18.000 19.000 !
                 20.000 21.000 22.000 23.000 24.000 25.000 26.000 !
                 27.000 28.000 29.000 30.000
end hullLine
begin hullLine
station 0.250
        yOffsets  0.773  3.010  3.843  4.843  5.420  5.783  6.030 !
                  6.190  6.273  6.290  6.245  6.161  6.040  5.905 !
                  5.773  5.665  5.565  5.492  5.448  5.448  5.450 !
                  5.626  5.850  6.180  6.625  7.200  7.870  8.625 !
                  9.430 10.260 11.095 11.930
        zOffsets  0.000  0.500  1.000  2.000  3.000  4.000  5.000 !
                  6.000  7.000  8.000  9.000 10.000 11.000 12.000 !
                 13.000 14.000 15.000 16.000 17.000 18.000 19.000 !
                 20.000 21.000 22.000 23.000 24.000 25.000 26.000 !
                 27.000 28.000 29.000 30.000
end hullLine
begin hullLine
station 0.500
        yOffsets  2.190  4.746  5.735  6.968  7.771  8.344  8.761 !
                  9.061  9.272  9.410  9.493  9.533  9.541  9.522 !
                  9.486  9.451  9.425  9.417  9.435  9.492  9.510 !
                  9.670  9.950 10.290 10.728 11.214 11.774 12.394 !
                 13.062 13.763 14.486 15.223
        zOffsets  0.000  0.500  1.000  2.000  3.000  4.000  5.000 !
                  6.000  7.000  8.000  9.000 10.000 11.000 12.000 !
                 13.000 14.000 15.000 16.000 17.000 18.000 19.000 !
                 20.000 21.000 22.000 23.000 24.000 25.000 26.000 !
                 27.000 28.000 29.000 30.000
end hullLine
begin hullLine
```

```
station 0.750
        yOffsets  4.410  7.049  8.107  9.450 10.359 11.031 11.523 !
                 11.894 12.176 12.384 12.531 12.631 12.701 12.742 !
                 12.752 12.751 12.754 12.772 12.815 12.892 13.012 !
                 13.184 13.415 13.710 14.068 14.484 14.953 15.467 !
                 16.019 16.605 17.218 17.851
        zOffsets  0.000  0.500  1.000  2.000  3.000  4.000  5.000 !
                  6.000  7.000  8.000  9.000 10.000 11.000 12.000 !
                 13.000 14.000 15.000 16.000 17.000 18.000 19.000 !
                 20.000 21.000 22.000 23.000 24.000 25.000 26.000 !
                 27.000 28.000 29.000 30.000
end hullLine
begin hullLine
station 1.000
        yOffsets  6.830  9.603 10.671 12.049 12.989 13.688 14.210 !
                 14.612 14.918 15.147 15.315 15.434 15.524 15.587 !
                 15.630 15.658 15.687 15.725 15.780 15.860 15.973 !
                 16.126 16.324 16.570 16.863 17.202 17.582 18.001 !
                 18.454 18.937 19.446 19.975
        zOffsets  0.000  0.500  1.000  2.000  3.000  4.000  5.000 !
                  6.000  7.000  8.000  9.000 10.000 11.000 12.000 !
                 13.000 14.000 15.000 16.000 17.000 18.000 19.000 !
                 20.000 21.000 22.000 23.000 24.000 25.000 26.000 !
                 27.000 28.000 29.000 30.000
end hullLine
begin hullLine
station 1.500
        yOffsets 11.500 14.425 15.500 16.887 17.820 18.487 18.992 !
                 19.376 19.661 19.865 20.014 20.122 20.198 20.256 !
                 20.307 20.352 20.396 20.441 20.489 20.548 20.622 !
                 20.714 20.828 20.968 21.135 21.333 21.561 21.821 !
                 22.107 22.415 22.739 23.076
        zOffsets  0.000  0.500  1.000  2.000  3.000  4.000  5.000 !
                  6.000  7.000  8.000  9.000 10.000 11.000 12.000 !
                 13.000 14.000 15.000 16.000 17.000 18.000 19.000 !
                 20.000 21.000 22.000 23.000 24.000 25.000 26.000 !
                 27.000 28.000 29.000 30.000
end hullLine
begin hullLine
station 2.000
        yOffsets 15.400 18.239 19.289 20.626 21.487 22.093 22.532 !
                 22.849 23.073 23.226 23.331 23.401 23.448 23.479 !
```

```
                 23.503 23.522 23.542 23.561 23.584 23.615 23.653 !
                 23.701 23.761 23.837 23.930 24.040 24.169 24.313 !
                 24.472 24.643 24.823 25.010
        zOffsets  0.000  0.500  1.000  2.000  3.000  4.000  5.000 !
                  6.000  7.000  8.000  9.000 10.000 11.000 12.000 !
                 13.000 14.000 15.000 16.000 17.000 18.000 19.000 !
                 20.000 21.000 22.000 23.000 24.000 25.000 26.000 !
                 27.000 28.000 29.000 30.000
end hullLine
begin hullLine
station 3.000
        yOffsets 21.000 23.156 23.912 24.842 25.388 25.728 25.920 !
                 26.049 26.118 26.157 26.186 26.206 26.218 26.226 !
                 26.234 26.242 26.244 26.250 26.259 26.270 26.281 !
                 26.292 26.307 26.325 26.344 26.363 26.383 26.402 !
                 26.422 26.441 26.460 26.492
        zOffsets  0.000  0.500  1.000  2.000  3.000  4.000  5.000 !
                  6.000  7.000  8.000  9.000 10.000 11.000 12.000 !
                 13.000 14.000 15.000 16.000 17.000 18.000 19.000 !
                 20.000 21.000 22.000 23.000 24.000 25.000 26.000 !
                 27.000 28.000 29.000 30.000
end hullLine
begin hullLine
station 4.000
        yOffsets 23.770 25.367 25.853 26.310 26.473 26.499 26.500 !
                 26.500 26.500 26.500 26.500 26.500
        zOffsets  0.000  0.500  1.000  2.000  3.000  4.000  5.000 !
                 10.000 15.000 20.000 25.000 30.000
end hullLine
begin hullLine
station 5.000
        yOffsets 24.400 25.760 26.189 26.498 26.500 26.500 26.500 !
                 26.500 26.500 26.500 26.500
        zOffsets  0.000  0.500  1.000  2.000  3.000  5.000 10.000 !
                 15.000 20.000 25.000 30.000
end hullLine
begin hullLine
station 6.000
        yOffsets 24.400 25.760 26.189 26.498 26.500 26.500 26.500 !
                 26.500 26.500 26.500 26.500
        zOffsets  0.000  0.500  1.000  2.000  3.000  5.000 10.000 !
                 15.000 20.000 25.000 30.000
```

```
end hullLine
begin hullLine
station 8.000
        yOffsets 24.400 25.760 26.189 26.498 26.500 26.500 26.500 !
                 26.500 26.500 26.500 26.500
        zOffsets  0.000  0.500  1.000  2.000  3.000  5.000 10.000 !
                 15.000 20.000 25.000 30.000
end hullLine
begin hullLine
station 10.000
        yOffsets 24.400 25.760 26.189 26.498 26.500 26.500 26.500 !
                 26.500 26.500 26.500 26.500
        zOffsets  0.000  0.500  1.000  2.000  3.000  5.000 10.000 !
                 15.000 20.000 25.000 30.000
end hullLine
begin hullLine
station 12.000
        yOffsets 23.918 25.401 25.897 26.360 26.495 26.500 26.500 !
                 26.500 26.500 26.500 26.500 26.500
        zOffsets  0.000  0.500  1.000  2.000  3.000  4.000  5.000 !
                 10.000 15.000 20.000 25.000 30.000
end hullLine
begin hullLine
station 13.000
        yOffsets 22.197 24.053 24.766 25.590 26.022 26.249 26.381 !
                 26.460 26.495 26.500 26.500 26.500 26.500 26.500 !
                 26.500
        zOffsets  0.000  0.500  1.000  2.000  3.000  4.000  5.000 !
                  6.000  7.000  8.000 10.000 15.000 20.000 25.000 !
                 30.000
end hullLine
begin hullLine
station 14.000
        yOffsets 19.219 21.652 22.627 23.811 24.531 25.020 25.372 !
                 25.641 25.843 26.006 26.139 26.345 26.328 26.392 !
                 26.438 26.468 26.487 26.498 26.500 26.500 26.500 !
                 26.500
        zOffsets  0.000  0.500  1.000  2.000  3.000  4.000  5.000 !
                  6.000  7.000  8.000  9.000 10.000 11.000 12.000 !
                 13.000 14.000 15.000 16.000 17.000 20.000 25.000 !
                 30.000
end hullLine
```

```
begin hullLine
station 15.000
        yOffsets 15.111 18.139 19.326 20.848 21.854 22.603 23.194 !
                 23.662 24.052 24.376 24.656 24.890 25.101 25.295 !
                 25.468 25.619 25.751 25.869 25.978 26.078 26.168 !
                 26.246 26.312 26.365 26.408 26.443 26.468 26.486 !
                 26.497 26.500 26.500 26.500
        zOffsets  0.000  1.000  1.000  2.000  3.000  4.000  5.000 !
                  6.000  7.000  8.000  9.000 10.000 11.000 12.000 !
                 13.000 14.000 15.000 16.000 17.000 18.000 19.000 !
                 20.000 21.000 22.000 23.000 24.000 25.000 26.000 !
                 27.000 28.000 29.000 30.000
end hullLine
begin hullLine
station 16.000
        yOffsets 10.520 13.816 15.131 16.896 18.115 19.046 19.798 !
                 20.423 20.956 21.424 21.845 22.256 22.576 22.904 !
                 23.216 23.512 23.793 24.061 24.315 24.559 24.792 !
                 25.015 25.227 25.427 25.614 25.787 25.943 26.084 !
                 26.208 26.316 26.409 26.488
        zOffsets  0.000  1.000  1.000  2.000  3.000  4.000  5.000 !
                  6.000  7.000  8.000  9.000 10.000 11.000 12.000 !
                 13.000 14.000 15.000 16.000 17.000 18.000 19.000 !
                 20.000 21.000 22.000 23.000 24.000 25.000 26.000 !
                 27.000 28.000 29.000 30.000
end hullLine
begin hullLine
station 17.000
        yOffsets  6.250  9.179 10.477 12.294 13.545 14.500 15.276 !
                 15.930 16.505 17.031 17.526 17.998 18.454 18.905 !
                 19.356 19.807 20.258 20.707 21.154 21.594 22.030 !
                 22.465 22.901 23.330 23.750 24.162 24.559 24.935 !
                 25.288 25.619 25.939 26.259
        zOffsets  0.000  1.000  1.000  2.000  3.000  4.000  5.000 !
                  6.000  7.000  8.000  9.000 10.000 11.000 12.000 !
                 13.000 14.000 15.000 16.000 17.000 18.000 19.000 !
                 20.000 21.000 22.000 23.000 24.000 25.000 26.000 !
                 27.000 28.000 29.000 30.000
end hullLine
begin hullLine
station 18.000
        yOffsets  2.828  4.846  5.947  7.385  8.385  9.159  9.791 !
```

```
                10.325 10.805 11.258 11.696 12.132 12.585 13.070 !
                13.599 14.175 14.795 15.453 16.146 16.868 17.609 !
                18.362 19.117 19.867 20.608 21.335 22.041 22.728 !
                23.394 24.030 24.463 25.254
        zOffsets  0.000  1.000  1.000  2.000  3.000  4.000  5.000 !
                 6.000  7.000  8.000  9.000 10.000 11.000 12.000 !
                13.000 14.000 15.000 16.000 17.000 18.000 19.000 !
                20.000 21.000 22.000 23.000 24.000 25.000 26.000 !
                27.000 28.000 29.000 30.000
end hullLine
begin hullLine
station 18.500
        yOffsets  1.603  3.043  3.853  4.929  5.685  6.273  6.756 !
                 7.159  7.527  7.874  8.221  8.587  8.992  9.453 !
                 9.989 10.610 11.320 12.106 12.952 13.841 14.758 !
                15.692 16.633 17.566 18.485 19.381 20.250 21.095 !
                21.914 22.700 23.455 24.191
        zOffsets  0.000  1.000  1.000  2.000  3.000  4.000  5.000 !
                 6.000  7.000  8.000  9.000 10.000 11.000 12.000 !
                13.000 14.000 15.000 16.000 17.000 18.000 19.000 !
                20.000 21.000 22.000 23.000 24.000 25.000 26.000 !
                27.000 28.000 29.000 30.000
end hullLine
begin hullLine
station 19.000
        yOffsets  0.798  1.510  1.943  2.545  2.952  3.286  3.564 !
                 3.790  3.998  4.193  4.401  4.647  4.946  5.354 !
                 5.873  6.540  7.365  8.318  9.339 10.387 11.459 !
                12.556 13.667 14.771 15.855 16.911 17.935 18.927 !
                19.885 20.808 21.699 22.565
        zOffsets  0.000  1.000  1.000  2.000  3.000  4.000  5.000 !
                 6.000  7.000  8.000  9.000 10.000 11.000 12.000 !
                13.000 14.000 15.000 16.000 17.000 18.000 19.000 !
                20.000 21.000 22.000 23.000 24.000 25.000 26.000 !
                27.000 28.000 29.000 30.000
end hullLine
begin hullLine
station 19.500
        yOffsets  0.000  0.251  0.235  0.229  0.211  0.199  0.221 !
                 0.238  0.252  0.265  0.277  0.288  0.322  0.444 !
                 0.712  1.186  1.948  2.987  4.140  5.306  6.476 !
                 7.667  8.880 10.106 11.330 12.541 13.728 14.881 !
```

```
                 15.997 17.077 18.124 19.145 20.152
        zOffsets  0.000  0.000  1.000  1.000  2.000  3.000  4.000 !
                  5.000  6.000  7.000  8.000  9.000 10.000 11.000 !
                 12.000 13.000 14.000 15.000 16.000 17.000 18.000 !
                 19.000 20.000 21.000 22.000 23.000 24.000 25.000 !
                 26.000 27.000 28.000 29.000 30.000
end hullLine
begin hullLine
station 20.000
        yOffsets  0.000  0.792  2.043  3.312  4.591  5.874  7.159 !
                  8.438  9.701 10.939 12.146 13.325 14.482 15.619 !
                 16.741
        zOffsets 17.000 17.000 18.000 19.000 20.000 21.000 22.000 !
                 23.000 24.000 25.000 26.000 27.000 28.000 29.000 !
                 30.000
end hullLine
begin hullLine
station 20.300
        yOffsets  0.000  0.312  1.628  2.941  4.243  5.533  6.811 !
                  8.074  9.317 10.544 11.758 12.959 14.141
        zOffsets 19.000 19.000 20.000 21.000 22.000 23.000 24.000 !
                 25.000 26.000 27.000 28.000 29.000 30.000
end hullLine
begin hullLine
station 20.600
        yOffsets  0.000  1.090  2.374  3.645  4.905  6.170  7.435 !
                  8.698  9.957 11.222
        zOffsets 21.000 22.000 23.000 24.000 25.000 26.000 27.000 !
                 28.000 29.000 30.000
end hullLine
end patch
##########################################################
begin patch
label Lower hull forward of FP
normalRanges 0.0 1.0  0.0 1.0 -1.0 1.0
areaPanelLimit 2.0
begin hullLine
station -0.490
        yOffsets  0.000
        zOffsets  4.000
end hullLine
begin hullLine
```

```
station -0.390
        yOffsets  0.000  1.370  1.710  1.790  1.640  1.200  0.355 !
                  0.000
        zOffsets  1.000  2.000  3.000  4.000  5.000  6.000  7.000 !
                  7.000
end hullLine
begin hullLine
station -0.290
        yOffsets  0.000  0.710  1.330  1.985  2.310  2.380  2.230 !
                  1.890  1.370  0.730  0.000
        zOffsets  0.000  0.500  1.000  2.000  3.000  4.000  5.000 !
                  6.000  7.000  8.000  9.000
end hullLine
begin hullLine
station -0.200
        yOffsets  0.000  1.235  1.790  2.460  2.780  2.850  2.740 !
                  2.460  2.060  1.530  0.970  0.405  0.000
        zOffsets  0.000  0.500  1.000  2.000  3.000  4.000  5.000 !
                  6.000  7.000  8.000  9.000 10.000 11.000
end hullLine
begin hullLine
station -0.100
        yOffsets  0.000  0.015  1.580  2.180  2.880  3.205  3.300 !
                  3.235  3.030  2.720  2.315  1.885  1.440  0.940 !
                  0.460  0.000
        zOffsets  0.000  0.000  0.500  1.000  2.000  3.000  4.000 !
                  5.000  6.000  7.000  8.000  9.000 10.000 11.000 !
                 12.000 13.000
end hullLine
begin hullLine
station 0.000
        yOffsets  0.000  0.105  1.920  2.570  3.315  3.688  3.830 !
                  3.819  3.690  3.490  3.240  2.950  2.640  2.295 !
                  1.935  1.550  1.155  0.760  0.420  0.170  0.000
        zOffsets  0.000  0.000  0.500  1.000  2.000  3.000  4.000 !
                  5.000  6.000  7.000  8.000  9.000 10.000 11.000 !
                 12.000 13.000 14.000 15.000 16.000 17.000 18.000
end hullLine
end patch
#####################################################
begin patch
label Upper hull forward of FP
```

```
normalRanges 0.0 1.0  0.0 1.0 -1.0 0.0
begin hullLine
station -0.263
        yOffsets  0.000
        zOffsets 30.000
end hullLine
begin hullLine
station -0.200
        yOffsets  0.000  2.340  3.620
        zOffsets 28.000 29.000 30.000
end hullLine
begin hullLine
station -0.100
        yOffsets  0.000  1.550  2.795  3.825  4.825  5.800
        zOffsets 25.000 26.000 27.000 28.000 29.000 30.000
end hullLine
begin hullLine
station 0.000
        yOffsets  0.000  0.915  1.910  2.940  3.935  4.910  5.880 !
                  6.820  7.760
        zOffsets 22.000 23.000 24.000 25.000 26.000 27.000 28.000 !
                 29.000 30.000
end hullLine
end patch
#########################################################
begin patch
label Transom
normalRanges -1.0 -1.0  0.0 0.0 0.0 0.0
begin hullLine
station    20.600
        yOffsets 11.222
        zOffsets 30.000
end hullLine
begin hullLine
station    20.600
        yOffsets  9.957  9.957
        zOffsets 29.000 30.000
end hullLine
begin hullLine
station    20.600
        yOffsets  8.698  8.698
        zOffsets 28.000 30.000
```

```
end hullLine
begin hullLine
station    20.600
        yOffsets  7.435  7.435
        zOffsets 27.000 30.000
end hullLine
begin hullLine
station    20.600
        yOffsets  6.170  6.170
        zOffsets 26.000 30.000
end hullLine
begin hullLine
station    20.600
        yOffsets  4.905  4.905
        zOffsets 25.000 30.000
end hullLine
begin hullLine
station    20.600
        yOffsets  3.645  3.645
        zOffsets 24.000 30.000
end hullLine
begin hullLine
station    20.600
        yOffsets  2.374  2.374
        zOffsets 23.000 30.000
end hullLine
begin hullLine
station    20.600
        yOffsets  1.090  1.090
        zOffsets 22.000 30.000
end hullLine
begin hullLine
station    20.600
        yOffsets  0.000  0.000
        zOffsets 21.000 30.000
end hullLine
end patch
############################################################
begin patch
label Deck
normalRanges 0.0 0.0  0.0 0.0 1.0 1.0
begin hullLine
```

```
station    -0.263
        yOffsets  0.000
        zOffsets 30.000
end hullLine
begin hullLine
station    -0.200
        yOffsets  3.620  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station    -0.100
        yOffsets  5.800  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station     0.000
        yOffsets  7.760  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station     0.250
        yOffsets 11.930  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station     0.500
        yOffsets 15.223  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station     0.750
        yOffsets 17.851  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station     1.000
        yOffsets 19.975  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station     1.500
        yOffsets 23.076  0.000
```

```
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station     2.000
        yOffsets 25.010  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station     3.000
        yOffsets 26.492  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station     4.000
        yOffsets 26.500  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station     5.000
        yOffsets 26.500  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station     6.000
        yOffsets 26.500  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station     8.000
        yOffsets 26.500  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station    10.000
        yOffsets 26.500  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station    12.000
        yOffsets 26.500  0.000
        zOffsets 30.000 30.000
end hullLine
```

```
begin hullLine
station    13.000
        yOffsets 26.500  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station    14.000
        yOffsets 26.500  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station    15.000
        yOffsets 26.500  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station    16.000
        yOffsets 26.488  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station    17.000
        yOffsets 26.259  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station    18.000
        yOffsets 25.254  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station    18.500
        yOffsets 24.191  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station    19.000
        yOffsets 22.565  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station    19.500
```

```
        yOffsets 20.152  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station    20.000
        yOffsets 16.741  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station    20.300
        yOffsets 14.141  0.000
        zOffsets 30.000 30.000
end hullLine
begin hullLine
station    20.600
        yOffsets 11.222  0.000
        zOffsets 30.000 30.000
end hullLine
end patch
end patchHull
```

C.3 SM3DRadDif Input File EssoOsakaRadDif.inp for Esso Osaka

```
begin SM3DRadDif
label Esso Osaka from manuevering trials by Crane, 1979 SNAME Trans.
wetPanelFileName EssoOsakaWetPanelHull.pkl
radDifDBFileName EssoOsakaRadDifDB.pkl
loadCondition 1025.0 21.73 0.0 19.0
hydroCompOptions 0.8 1.0e6 5.0 5.0 sourceGauss Galerkin 2
enFreqRange 0.05 3.0 0.05
begin condLimits
    enFreqsLongLimits 0.5  3.0
    condLimitsLong    2000 2000
    enFreqsLatLimits  0.5  3.0
    condLimitsLat     1500 1500
end condLimits
speedKnotsRange 0.0 15.0 3.0
seaDirDegRange 0.0 180.0 15.0
waveFreqRange 0.1 2.0 0.1
diffracOption diffrac
plotOption screen
end SM3DRadDif
```

C.4 SM3DBuildShip Input File EssoOsakaBuildShip.inp for Building Time Domain Ship Model of Esso Osaka

```
begin SM3DBuildShip
label Esso Osaka with experimental maneuvering coefficients
shipType freeTD
radDifDBFileName EssoOsakaRadDifDB.pkl
shipDBFileName EssoOsakaFreeShip.pkl
dryPanelOption noDryPanel
loadCondition 1025.0 21.73 0.0 19.0
correctionGM 0.0
gyradii 21.2 81.25 81.25
tRetardIncMax 0.2 40.0
enFreqIntIncMax 0.05 4.0
begin hullViscous
    speedsResistKnots 2.0  16.0  18.0    19.6    21.2   22.9
    resistOption InputResist
    resistCos 0.00306 0.00306 0.00308 0.00328 0.00370 0.00426
    hullDragCo 1.17 0.0
end hullViscous
begin hullManeuver
    hullManMethod inputManCo
    #  Hull coefficients from Table 5.2 of ITTC 2002 Esso Osaka,
    #  adjusted for force at CG
    #           yv   yr    nv      nr    yvv      yvr    yrr
    #          nvr2   nrr    nrv2
    hullManCo -0.383 0.098 -0.135 -0.051 -0.276  -0.242  -0.011 !
              0.024  -0.017  -0.297
    inputManCoOptions stabilityAxes zero
end hullManeuver
begin appendages
    begin rudder
        pairOption single
        label Rudder
        dimen 20.2 0.0 14.0 13.85 9.0 9.0 -90.0
        incFlowCo 0.0 0.4
        autopilotParam 35.0 3.0 0.0 3.0 0.85 0.1
        dispGains 0.0 0.0 0.0 0.0 0.0 -3.8
        velGains 0.0 0.0 0.0 0.0 0.0 -10.0
    end rudder
```

```
end appendages
begin propellers
    begin fixedPitchPropeller
        pairOption single
        label Propeller
        dimen 19.8 0.0 5.0 9.10
        propCo 0.352 0.20
        thrustCoQuadratic 0.394 -0.197 -0.148
        propControlParam 0.0 200.0 -5.0 -1.0 5.0 0.8 20.0 0.0 0.0
    end fixedPitchPropeller
end propellers
begin rudderPropCo
    rudderPropCo 0 0.66
end rudderPropCo
shipPlotOutOption screenFile
begin shipPlots
    shipPlotOptions png hullAppProp includeStarboard nonSmooth
    shipPlotFileName shipAftLowerView.png
    viewPoint -300.0 300.0 -150.0
    zoomFactor 2.0
    imageSizeShip 300.0 200.0
    cropStations -1.0e6 1.0e6
    #
    shipPlotOptions png hullAppProp includeStarboard nonSmooth
    shipPlotFileName shipAftView.png
    viewPoint -300.0 0.0 0.0
    zoomFactor 1.0
    imageSizeShip 150.0 100.0
    cropStations -1.0e6 1.0e6
end shipPlots
retardPlotOption screen
rpmSpeedOption rpmSpeed
paramRpmSpeed 1 100.0 0.2 300.0
indicesPropRpm 0
speedsKnotsRpm 7.7 10.0
end SM3DBuildShip
```

C.5 SM3DFreeMo Input File turn10ktFreeMo.inp for Esso Osaka Turning Circle at 10 knots

```
begin SM3DFreeMo
label Esso Osaka turn circle at 10 knots
freeShipDBTDFileName EssoOsakaFreeShip.pkl
loadCondition 1025.0 21.73 0.0 19.0 0.0
seawayOption calm
timeParameters 0.5 0.0 20.0 20.0
nonLinearOption linear
dispsFixed0MDeg 0.0 0.0 0.0 0.0 0.0 0.0
speed0Knots 10.0
rudderDeflects0Deg 0.0
rudderVels0Deg 0.0
rpmsPropellers0 51.111 51.111
begin maneuvers
    setRudder -1 35.0
    elapsedTime 2000.0
end maneuvers
outTimeIntervals 1.0 100.0
outTimeSeries disp vel noAcc
outRudderProp noRudder noProp
plotOption screen
end SM3DFreeMo
```

This page intentionally left blank.

Distribution List

LIST PART 1: Internal Distribution by Centre

1 Author (1 hard copy)

5 DRDC Atlantic Library (1 hard copy)

3 Project Officer ABCA-02-01 (CSci) for distribution

12 Project Officer ABCANZ-97-12 (H/WP) for distribution (12 hard copies)

---

21 TOTAL LIST PART 1 (7 CD, 14 HARD COPIES)

LIST PART 2: External Distribution by DRDKIM

1 Library and Archives Canada

1 DRDKIM 3

1 DMSS 2
555 Blvd. De la Carriere
Gatineau, Quebec
K1A 0K2

1 Canadian Forces Maritime Warfare School
Attention: Commanding Officer
PO Box 99000 STN Forces,
Halifax, N.S. B3K 5X5

1 Director General (1 hard copy)
Defence R&D Canada - Suffield
P.O. Box 4000
Medicine Hat, Alberta
T1A 8K6

1 Director-General
Institute for Ocean Technology
National Research Council of Canada
P.O. Box 12093, Station A
St. John's, Newfoundland
A1B 3T5

1 Canadian Coast Guard
Ship Safety Branch
Canada Building, 11th Floor
344 Slater Street
Ottawa, Ontario
K1A 0N7
Attn: Chief, Design and Construction

2 Commanding Officer (2 hard copies)
U.S. Coast Guard Research and Development Center
1082 Shennecosett Road
Groton, CT 06340-2602

1 Ministry of Defence
Attn: Head, Naval Research
Dept. of Naval Architecture and Marine Engineering and Development
P.O. Box 20702
2500 ES, The Hague
The Netherlands

1 FOI Swedish Defence Research Agency
Attn: Eva Dalberg
Grindsjon Research Centre
SE-147 25 Tumba
Sweden

1 Department of Defence (Navy Office)
Attn: Director Naval Ship Design
Campbell Park Office CPI-505
Canberra ACT 2600
Australia

1 Document Exchange Centre
Defence Information Services Branch
Department of Defence
Campbell Park Offices CP2-5-08
Canberra ACT 2600 Australia

1 Bundesamt fur Wehrtechnik und Beschaffung - SG I 3
Postfach 7360
6057 Koblenz
Germany

1 Dr. John Duncan
Defence Equipment and Support
Abbey Wood
Mail Point 8014
BRISTOL BS34 8JH
UK

---

15 TOTAL LIST PART 2 (13 CD, 2 HARD COPIES)

36 TOTAL COPIES REQUIRED (20 CD, 16 HARD COPIES)

This page intentionally left blank.

DOCUMENT CONTROL DATA

(Security classification of title, abstract and indexing annotation must be entered when document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document). Defence R&D Canada - Atlantic	2. SECURITY CLASSIFICATION (overall security classification of the document including special warning terms if applicable) UNCLASSIFIED

3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C,R or U) in parentheses after the title.)

Validation of ShipMo3D Version 1.0 User Applications for Simulation of Ship Motions

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)

McTaggart, Kevin A.

5. DATE OF PUBLICATION (month and year of publication of document) August 2007	6a. NO. OF PAGES (total including Annexes, Appendices, etc). 150	6b. NO. OF REFS (total cited in document) 19

7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final.)

Technical Memorandum

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include address).

Defence R&D Canada - Atlantic, PO Box 1012, Dartmouth, NS, Canada B2Y 3Z7

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written.) 11GV05	9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written).
10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique.) DRDC Atlantic TM 2007-173	10b. OTHER DOCUMENT NOs. (Any other numbers which may be assigned this document either by the originator or by the sponsor.)

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

(X) Unlimited distribution
( ) Defence departments and defence contractors; further distribution only as approved
( ) Defence departments and Canadian defence contractors; further distribution only as approved
( ) Government departments and agencies; further distribution only as approved
( ) Defence departments; further distribution only as approved
( ) Other (please specify):

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected).

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

ShipMo3D is an object-oriented library with associated user applications for predicting ship motions in calm water and in waves. This report describes the validation of ShipMo3D user applications with data from model tests and full-scale trials. Seakeeping predictions have been validated with model tests for a steered warship model and with sea trials for a naval destroyer. Predicted RMS motions in random seas are typically within 10 to 30 percent of measured values, with heave motions being the most accurate and roll motions being the least accurate. Predicted zero-crossing periods for motions in random seas are typically within 10 percent of measured values. For the tanker Esso Osaka performing turning circle maneuvers, predicted turning circle parameters (tactical diameter, and speed and yaw rate at 1500 s), are within 18 percent of measured values from sea trials. Note that input data for the Esso Osaka included experimental hull maneuvering coefficients, and that less accurate results would be expected if maneuvering coefficients had to be estimated using other means.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title).

maneuvering
model tests
roll
sea trials
seakeeping
ship motions

This page intentionally left blank.

Defence R&D Canada

Canada's leader in defence
and National Security
Science and Technology

R & D pour la défense Canada

Chef de file au Canada en matière
de science et de technologie pour
la défense et la sécurité nationale

DEFENCE DÉFENSE

www.drdc-rddc.gc.ca